# MONTANA SUNPOWER

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## Volume 2:

## PASSIVE SOLAR HOMES

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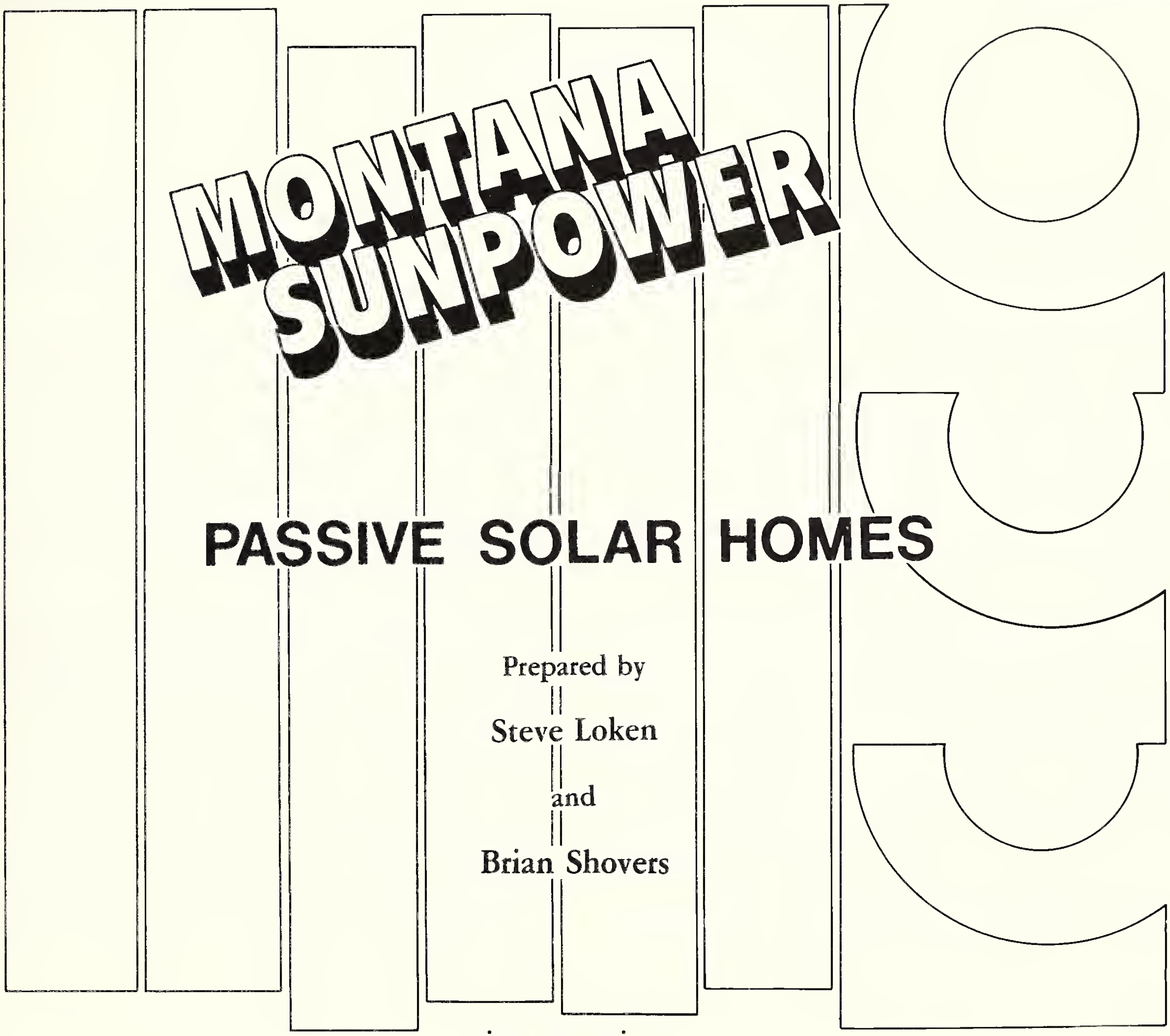

# MONTANA SUNPOWER

## PASSIVE SOLAR HOMES

Prepared by

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in cooperation
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# Preface

Heat from the sun—solar energy or "sunpower"—has warmed the earth since its beginning and played a predominant role in the planet's evolution. It melted the ice-age glaciers to form oceans and lakes, changed the world's climates and seasons, and sparked the growth of myriad life forms.

It also has influenced human development. Through the ages, people have used the sun's energy directly and indirectly to grow their crops, power their ships, and, in general, structure their lives. Experience taught them that crops needed the sun's warmth and light to grow, and that shelters facing the sun stayed warmer during cold periods.

Although the first fact, basic to agriculture, has never escaped our attention, the second probably deserves more notice than it has received. Historically, the traditional sources of heat—wood and coal—and the more recently developed sources that have largely taken their place—home heating oil, natural gas, and electricity—seemed to be obvious choices for meeting heating needs; these fuels were relatively cheap and there seemed to be no immediate shortage of supplies.

Now, however, dwindling supplies of nonrenewable fossil fuels and skyrocketing prices for those fuels have sparked an increased interest in finding alternative sources of energy. With this increased interest has come the growing realization that the same immense power that melted the glaciers might be used to heat our homes.

Montanans have long been known for their ingenuity and perseverance when faced with a challenge. Their response to the worldwide energy crisis of the last decade has been no exception. All across the state, enterprising Montanans from many different backgrounds have spent and are continuing to spend time, effort, and money to develop systems to capture the heat from the sun.

The first two volumes of the *Montana Sunpower* series highlight the efforts of some Montanans to use the sun's energy to heat their homes. These volumes, which describe active and passive solar homes, are surveys of existing residential solar systems. As such, they address the benefits and detriments, problems and solutions, and performance and livability of selected solar homes in the state. Future volumes in the series will discuss heat load calculations, solar retrofits, and solar systems on large buildings. This series is augmented by other publications from the Department of Natural Resources and Conservation (DNRC).

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The department also wishes to thank the many homeowners, solar designers, and project developers whose assistance and cooperation made this effort possible.

## FUNDING

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# Introduction

During the last several years, rising costs for conventional fuels have led to an increased use of passive solar building design in northern climes where people have long been skeptical about using the sun to heat their homes. Although passive solar technology has been used successfully for years in the southwestern states, where the sun shines regularly, the question remains: ''Can it work effectively and economically in Montana, where winters are long and the sun shines intermittently?''

The answer is yes. An 1,800-square-foot passive solar house near Billings meets approximately 70 percent of its winter heating needs with energy from the sun. In the cloudier northwestern corner of the state, a passively heated''envelope'' home required only one cord of wood to supplement solar heating through the mild winter of 1980-81. According to the owner, this is the most comfortable home in which his family has lived.

This second volume of the *Montana Sunpower* series examines 35 passive solar homes and greenhouses in Montana's principal climatic regions, ranging from the narrow mountain valleys in the northwest to the open plains in the southeastern part of the state. Several of the systems discussed in this volume were partially financed through the Renewable Energy Program of DNRC. Discussions of these grant projects, which are so noted in the text, generally contain more detailed accounts of system costs than the other narratives. Also, these DNRC-funded projects can be visited by the public if prior arrangements are made with the owners.

This volume does not present a comprehensive listing of passive solar homes in Montana. To list all of them would have been an exhausting, if not impossible, task. In selecting homes to be included, emphasis was given to systems that are most affordable, are cost-effective, and contribute significantly to the total heating and cooling needs of the home. An attempt also was made to provide an equitable geographic representation of homes from across the state.

DNRC project reports, as well as on-site interviews with solar home owners, designers, and builders, have provided information on how different passive solar designs perform in Montana. Although thorough scientific monitoring data is available in some cases, the primary emphasis here was to present a subjective evaluation by the owners themselves concerning comfort, energy savings, costs, construction problems, financing, and ways in which designs might be improved.

This book is not a design manual. Rather, it presents case studies of existing passively heated homes. As bankers, contractors, and home buyers become more interested in energy-efficient buildings, they need to know more about the effectiveness and cost of those passive solar homes already occupied in Montana. Thus, the information presented in this book should be helpful to many Montanans.

# How To Use This Book

The information in this volume is organized around four climate zones that reflect differences in the severity of the weather and the availability of sunshine for space heating. Each section begins with a map showing the boundaries of a particular zone and a brief description of its distinctive characteristics: general topography, average seasonal temperatures and extremes, average wind velocity and direction, solar radiation and average cloud cover during the heating season, and the annual number of heating degree-days, a measure of the relative severity of a given winter.

Although these climatic differences should influence the design of any residence, they are especially critical in passive solar design. Thus, in the building narratives that follow, climate is discussed as it applies directly to a specific design. For example, wind is a primary design consideration in eastern Montana; therefore, earth-sheltering is suggested as a way to lessen heat loss from a number of the homes east of the Continental Divide. This design type also is effective in areas with high seasonal heating and cooling demands.

Each narrative also includes specific information about a building's design, construction, and solar system, as well as the owner's assessment of system performance. A photograph of the home's exterior and a floorplan accompanies each narrative. The resource list found in the appendices provides a list of the glazing, insulation, and building materials manufacturers mentioned in this volume.

The concluding remarks that follow the building narratives highlight particular projects that demonstrate the simplicity, affordability, and effectiveness of passive solar design throughout Montana. The reader should be aware that passive solar technology is still relatively new to Montana and that the buildings being designed and constructed today will add to our knowledge and understanding of passive solar design.

# Principles of Passive Solar

For purposes of this survey, passive solar is defined as a technology that uses integral elements of a building's design to collect, store, and distribute heat through the natural processes of radiation, conduction, or convection. Mechanical pumps and fans are not used in true passive solar systems.

Passive systems offer two basic advantages over active systems. First, the components of a passive solar system often serve a structural or architectural purpose in addition to their heat-collecting or distributing functions. For example, south-facing windows in a passive solar building act as solar collectors as well as openings for natural lighting and summer cooling of the interior living space. Also, because passive solar systems require neither the high temperature flatplate collectors necessary with an active solar system nor the accompanying system of plumbing and pumps to distribute the heat, they are usually easier and less expensive to install.

## DESIGN TYPES

There are two common types of passive solar systems—direct gain and indirect gain.

The direct gain system is the more common and simpler of the two. In this type of system, a building is heated directly through windows facing south. Massive floor and wall materials absorb solar heat and reradiate it directly into the living space.

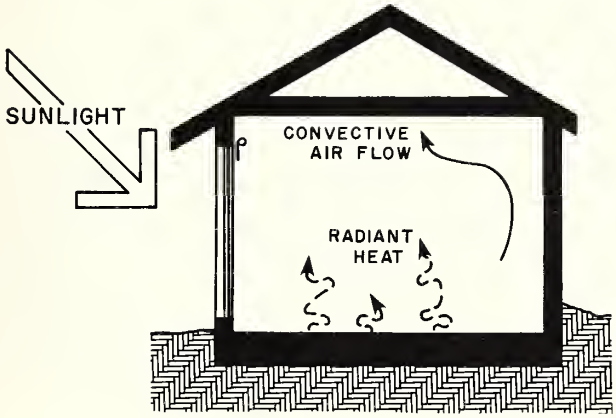
In an indirect gain system, sunlight is intercepted immediately behind the south windows by a massive thermal storage wall. This wall, which may employ masonry, concrete, or water to store heat, releases that heat into the living space behind the wall. Although this type of system is often more expensive than a direct gain system, it effectively reduces temperature fluctuations. The Trombe wall, one type of thermal storage wall, has vents at the top and bottom to permit a convective flow of air between the living space and the heated area behind the windows.

One variation of the indirect gain system employs an air- or liquid-filled flatplate collector to absorb heat. This system type is often referred to as isolated gain. The collector medium, once heated, flows through ducts into a storage bin containing rocks or into a tank filled with water. Heat then can be drawn from the storage mass to warm the living space. Such collectors are normally set away from the buildings they heat.

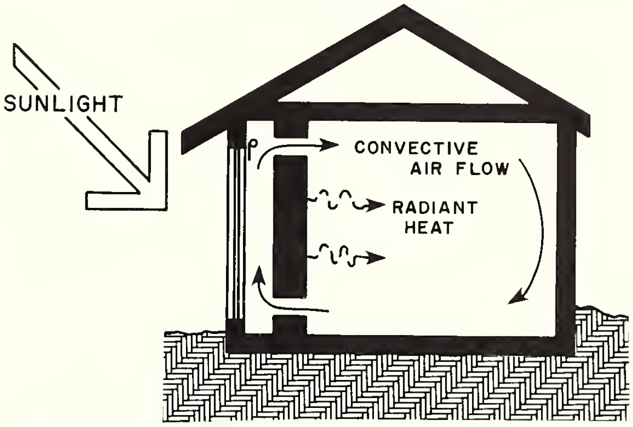
For a more complete discussion of these systems, see Mazria's *The Passive Solar Energy Book*.

Popular passive solar components are greenhouses and sunspaces. Although basically similar in design and appearance, these integrated solar collectors have slightly different functions. In a traditional greenhouse, primary emphasis is on maintaining an environment conducive to plant growth. A sunspace or solarium, on the other hand, is designed to provide additional living space for use as weather permits. These use considerations are not lost in passive solar design, although contributing heat to the house often is an important function of both the greenhouse and the sunspace. These solar units often incorporate both direct and indirect gain features.

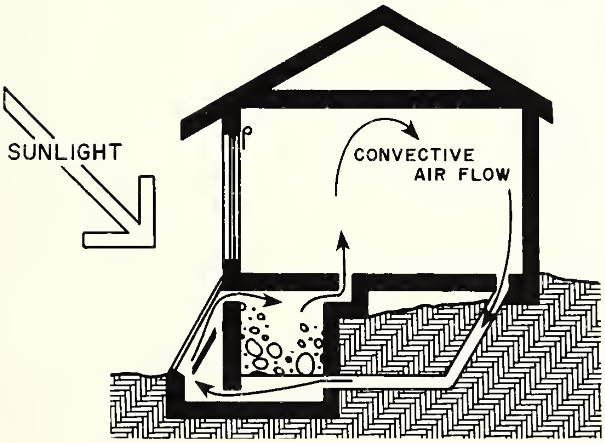
**DIRECT GAIN**



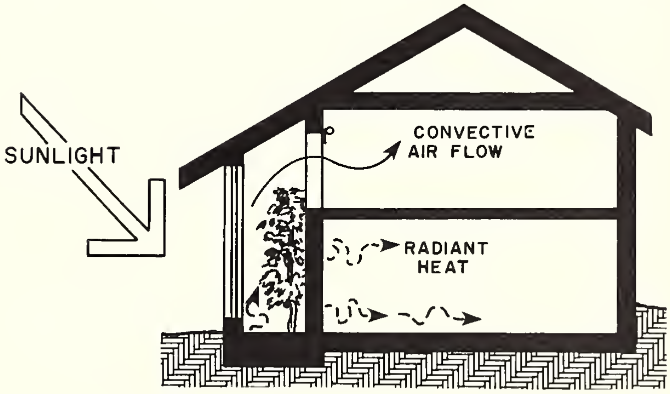
**INDIRECT GAIN**



**ISOLATED GAIN**



**SUNSPACE**



# Design Considerations

The performance of passive solar heating systems is greatly affected by climate and an area's surface features—landforms, slope, and vegetation. Because these factors are so important to passive system performance, and because Montana is a large state with regional variations in climate and topography, each project discussed in this volume was placed into one of four climate zones: northwestern Montana, southwestern Montana, northeastern Montana, or southeastern Montana.

## CLIMATE

Across Montana, four basic climatic characteristics—the amount and intensity of available sunlight, average summer and winter temperatures, wind speed and direction, and precipitation—have a dominant influence on passive solar design.

### Sunlight

Cloud cover and insolation (a more common term for incident solar radiation—the amount of solar radiation that strikes a surface exposed to the sky) vary greatly throughout the state. A passive solar designer uses insolation data to determine the amount of glazing necessary to provide total or supplemental solar heating for a particular building. The building's location and orientation, its profile, and window placement and sizing can be designed for greater efficiency if one knows the area's solar heating potential. Insolation data for Montana are available in the *Montana Solar Data Manual* and *Montana Solar and Weather Information*. Both publications are available from DNRC.

### Average Summer and Winter Temperatures

Meteorological data recorded at weather stations across Montana help a passive solar designer estimate average heating requirements. Local degree-day measurements are commonly used to make this determination. One degree-day accrues for each degree the outside temperature falls below a fixed reference point, usually 65°F, during a 24-hour period. For example, if the outside air temperature holds at 30°F over a 24-hour period, then 35 degree-days accrue. The method assumes that if the outside temperature is 65°F or higher, no heating is needed to maintain an inside comfort level of 65°F.

Daily degree-day totals are added to determine average annual degree-days. This average provides a measure of the relative severity of the October-to-May heating season. Montana's climate ranges from a high of 11,316 degree-days annually at Cooke City, the community with the coldest overall heating season temperatures in Montana, to a low of 6,684 degree-days annually at Thompson Falls, the community with the warmest overall heating season temperatures.

### Wind Speed and Direction

Wind can increase conductive heat loss and infiltration of cold air if a designer ignores its effect. Because winds are often strong and sustained east of the Continental Divide, they are a dominant design factor in this region. During the October-to-May heating season, prevailing winds carry arctic weather systems that can produce extreme wind chill factors. A designer can compensate for temperature extremes by altering a building's profile, configuration, and siting. Designers also should consider ways to use the wind to increase passive cooling and ventilation during the summer.

### Precipitation

Monthly precipitation data help the designer determine seasonal cloud cover, available sunshine, and the potential for using passive solar design in a specific area. For example, Libby's climate is characterized by high amounts of precipitation and lengthy periods of

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cloudiness during the heating season. In contrast, the Billings climate is characterized by low amounts of precipitation and a greater percentage of sunshine during the winter.

Inversion fog, caused by cool, dense air settling in valleys and low areas, is common throughout northwestern Montana during the spring and fall. Because this fog reduces the amount of solar radiation available for home heating, it is more challenging to design an efficient passive solar building for this region. In such a building, both thermal storage and movable insulation are important design considerations.

Precipitation, however, does not always cause design problems. Snow cover, for instance, increases the reflection of sunlight into vertical south-facing windows, thereby increasing the efficiency of a passive solar design.

## SURFACE FEATURES

The ways in which topography influences precipitation, wind speed and direction, and air temperatures in the different regions of Montana will be discussed in detail in the individual climate summaries for each zone. However, some general observations about the effects of landforms and vegetation on passive solar performance should be mentioned.

### Landforms

Surrounding landforms such as hills, valleys, and bodies of water can be used by the designer to temper climatic effects. For example, a south-facing hillside can be used to shelter a building from infiltration of cold air and conductive heat loss caused by wind and cold temperatures. Structures on flat sites can be sheltered by placing a ''berm'' or mound of earth against the structure to cover the foundation and, sometimes, the north wall. Proper drainage, waterproofing, structural design, and insulation must be considered before backfilling earth against a building. Also, since valleys have a tendency to collect cold air and fog, a building site above the valley floor is recommended for passively heated structures.

In most cases, north slopes, steep slopes, and heavily timbered building sites should be avoided. North slopes are generally colder, more shaded, and wetter than open, south-facing slopes. In addition, building on steep slopes and high ground-water areas may add to construction costs and often can present drainage problems.

### Vegetation

Although landscaping is normally one of the last things considered when constructing conventional homes, planting trees and shrubs and contouring the site should be primary considerations when designing a passive solar home. U.S. Department of Agriculture fact sheet number 235 describes the ability of windbreaks to reduce heat loss from a conventional house. The agency monitored two identical farmhouses in Nebraska, each of which maintained a 70°F indoor temperature throughout the winter; the house protected by a windbreak consumed 23 percent less energy than the house without a windbreak.

Windrows of evergreen trees and shrubs, planted on the side of the house exposed to prevailing winter winds, help to protect the building from air infiltration and, thus, make a passive solar heating system more efficient. Also, foundation plantings along the perimeter of a house help to reduce infiltration of air and conductive heat loss from the foundation. Evergreens planted on the east and west sides help to shade the building from the hot summer sun. Deciduous trees, which shed their leaves in the fall, allow solar gain during the winter and provide shade during the summer if they are planted on the south side of a building.

# ZONE I

## Northwestern Montana

# The Land and Its Climate

The jumble of mountain ranges in northwestern Montana—from the Bitterroots, Cabinets, and Purcells on the western edge to the great ranges of the Continental Divide on the east—presents a barrier to the dominant west-to-east air flow. These ranges markedly affect precipitation in the surrounding valleys and thus make it difficult to generalize about the climate in this area.

Yearly precipitation in this zone ranges from a high of 28 inches in the heavily forested valleys near Troy to a low of 8 inches in the sparsely vegetated area around Lonepine, west of the Mission Valley. Climatologists describe the Kootenai and Clark Fork River valleys as a "modified Pacific maritime" region, characterized by heavy cloud cover and precipitation from late fall through early spring, and by considerably milder winter temperatures than the region east of the Continental Divide. However, most of the moisture carried east by the Pacific air masses is deposited on the western slopes of the Bitterroot Mountains; Missoula and Hamilton are in a rain shadow and receive only 12 to 15 inches of precipitation per year. The mountain valleys become progressively drier east of Missoula.

The Continental Divide shields northwestern Montana from the wind and arctic air that dominate the plains to the east. An arctic air mass occasionally will spill over the divide, causing relatively high winds—30 to 40 miles per hour—and subzero temperatures. Flathead Lake has a moderating influence on temperatures in Kalispell, at the north end of the lake, and in Polson, at the foot of the lake.

Winter temperatures throughout the valleys in this climate zone average 36 °F; subzero temperatures occur only a few times during an average winter. Thompson Falls, protected by the Bitterroots to the southwest and the Cabinets to the northwest, is the most temperate site in the state, with an average of 6,684 heating degree-days per year. Summer temperatures average 62 °F throughout the zone.

Winds throughout the area are generally inconsistent and light, due primarily to the influence of the numerous mountain ranges. During the October-to-May heating season, prevailing winds are from the west-northwest; westerly winds prevail during the remainder of the year. In northwestern Montana, wind does not have the critical influence on passive solar design that it does east of the Continental Divide.

During the heating season, the area receives an average of 35 to 45 percent of the sunshine possible for that period. Extended periods of cloudiness and fog are common during the winter. Sunny days are most frequent during summer and early autumn.

### CLIMATE SUMMARY

A) 35-45% possible sunshine* during heating season; moderate to high cloud cover

B) Insolation on vertical south wall during average heating season:
Missoula — 638 Btu/ft$^2$/day
Kalispell — 795 Btu/ft$^2$/day

C) 7,946 annual degree-days averaged over all stations in zone

D) Wind — moderate to low

E) Temperatures:
Average January temp. (F°) for zone: 22.6
Average August temp. (F°) for zone: 65.6

* The actual hours of sunshine divided by the possible hours of sunshine, expressed as a percentage.

**Sources:** *WSUN #8 Montana Solar and Weather Information, Montana Solar Data Manual, Montana Renewable Energy Handbook.*

# Design Criteria For Zone I

Because winters in this zone are usually rather mild and because winter skies here are cloudy approximately two-thirds of the time, the amount of heat required by homes in this zone is generally lower than in other parts of the state. Although increased cloud cover in the winter reduces the amount of solar radiation available for heating, it also acts as an atmospheric blanket to trap daytime heat and to maintain warmer temperatures at night, thus reducing winter heating demands. In the summer, temperatures in the valley bottoms generally drop at night, reducing summer cooling requirements.

## ELEMENTS OF DESIGN

A direct gain passive heating system generally will perform better than an indirect or isolated gain system in this zone because the low amounts of diffuse sunlight available may not effectively heat a thermal storage wall.

## GLAZING AND THERMAL STORAGE

Long periods of cloudiness require a larger than usual collector area relative to the number of degree-days so that as much solar energy as possible can be gained when the sun is shining. Also, to effectively store the heat during periods of cloudy weather requires a proportionately larger thermal mass.

Doug Balcomb and the Los Alamos Scientific Labs have developed a method for determining the amount of glazing necessary to obtain a certain passive solar heating fraction, assuming a predetermined heating load.[1] For instance, if a building has a heat loss of 6 Btu per degree-day per square foot of floor space—which implies a building with a ceiling insulated to R-30, R-19 walls, double-glazed windows, and a low infiltration rate of ¾ air change per hour—it's possible to calculate how much energy can be saved by installing enough south-facing windows to equal a certain percentage of the total floor area. Such calculations indicate that a south window area that constitutes 18 to 36 percent of the total floor area can be expected to reduce the annual heating load of a Missoula home by 15 to 16 percent, or by 47 to 68 percent if R-9 nighttime window insulation is used. The importance of nighttime insulation to retain solar heat gained during the day is quite evident in this example. (A list of window insulation types, manufacturers, and performance data appears in the appendices.) The home mentioned employed a combined direct and indirect solar gain system.

A common rule of thumb for determining the amount of thermal mass needed to obtain a certain percentage of space heating from the sun is as follows: for each square foot of south glazing, multiply the desired percentage of solar heating by .6 if a water mass is to be used for storage, or by 3 if masonry is to be used.

For example, a 1,600-square-foot house in Missoula with 288 square feet of south glazing and R-9 nighttime insulation would require 8,640 pounds of water or 43,220 pounds of masonry for heat storage if a desired solar heating fraction of 50 percent were to be achieved. Because the cost of adding thermal storage can be significant, this cost must be weighed against the energy that could be saved through its use.

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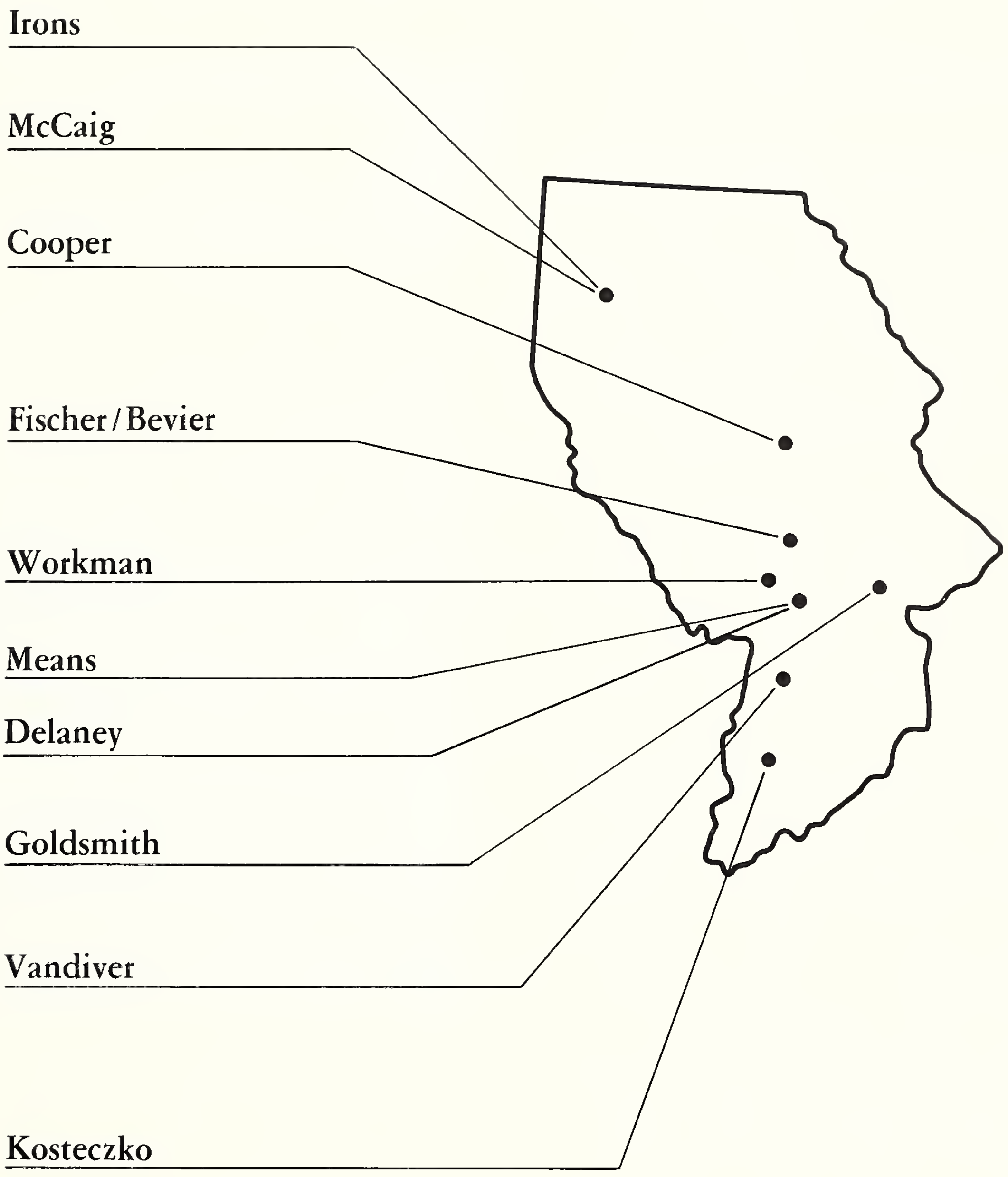
[1] See Balcomb, J.D., et al. *Passive Solar Design Handbook,* Volume II; DOE/CS-012712, ISBN-089934-128-4, 1981, 428 pp.



Irons
McCaig
Cooper
Fischer / Bevier
Workman
Means
Delaney
Goldsmith
Vandiver
Kosteczko

Libby

# Richard and Karen Irons

## BUILDING DESCRIPTION

This Cape Cod-style, three-bedroom ''envelope'' home sits on a terrace above Libby and the Kootenai River. Unique features of this house are its two-story solarium and double-walled construction on the north and south. The continuous airspace between the outer and inner walls forms a temperate blanket around the living space. The kitchen, dining room, and living room are adjacent to the solarium for increased exposure to available heat and light. A detached garage on the north is connected to a vestibule entry by a covered walkway.

Both the inner and outer shell of the envelope are well insulated. The exterior surface of the basement walls is waterproofed and covered with 3 inches of Styrofoam Blueboard® . The 2-by-6-inch studwalls on the east and west are insulated with 6 inches of fiberglass, as are the 2-by-6-inch exterior walls on the north and south. The inner walls on the north and the common wall between the living space and the solarium contain 3½ inches of fiberglass. The ceilings of both the living space and the attic are insulated with 6 inches of fiberglass. The inner surface of all perimeter walls, including the roof, is covered with a 6-mil polyethylene vapor barrier.

## SOLAR SYSTEM

Double glazing on the south solarium wall and roof covers 572 square feet. Interior temperatures and air distribution are controlled by opening and closing glass doors between the solarium and the living space.

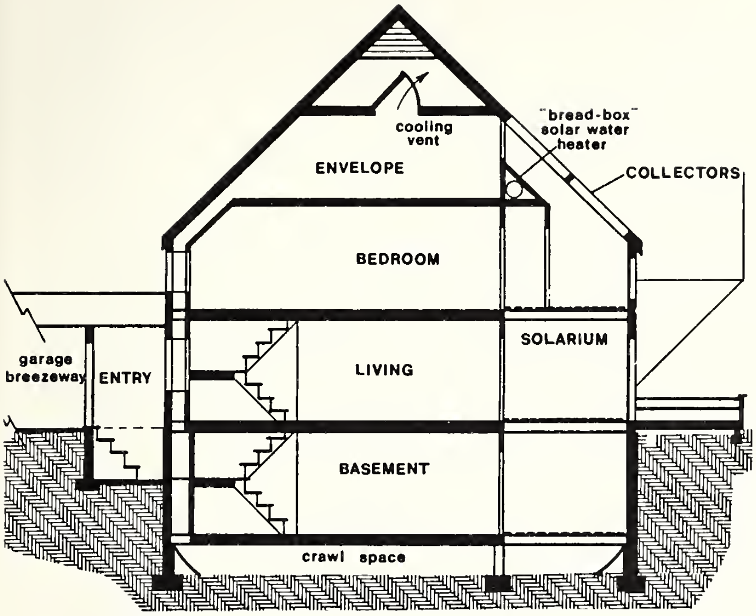
The designer of this envelope house describes system operation as follows: The heated solarium air becomes part of a convective air loop as it rises into the airspace or plenum. The air then moves down the 8-inch-wide airspace in the double north wall and into the crawlspace, where heat exchange occurs between the air and the soil of the crawlspace. During the day, warm air heats the soil; at night, the soil returns heat to the air. From the crawlspace, air returns to the solarium to complete the loop.

During the summer, excess heat is vented from the convective loop through a large thermal door in the attic ceiling. East-west gable vents also promote summer ventilation and enhance cooling.

A breadbox water heater was constructed inside the glazed solarium roof to preheat well water from 42 °F to about 100 °F before it enters an electric water heater. Preheating decreases the amount of electricity needed to heat the water.

## MAINTENANCE AND LIVABILITY

After living in their envelope house for over a year, the Irons seem satisfied with the way their passive heating system works. The interior living space receives adequate sunlight through the solarium, and the lack of excessive interior partitions allows for even interior heating. Humidity in the home averages 60 percent, which allows the occupants to remain comfortable at



cooler temperatures. The house uses very little auxiliary heat; the home's Vigilant® woodstove, the only backup heating source, used just over one cord of wood through an entire heating season. An overnight fire was never needed.

Summer cooling has not been a problem, according to the owners. Although temperatures in the upper bedroom can reach over 80 °F during the day, cool evenings help prevent overheating. Cooling could be improved by shading the roof glazing during the summer.

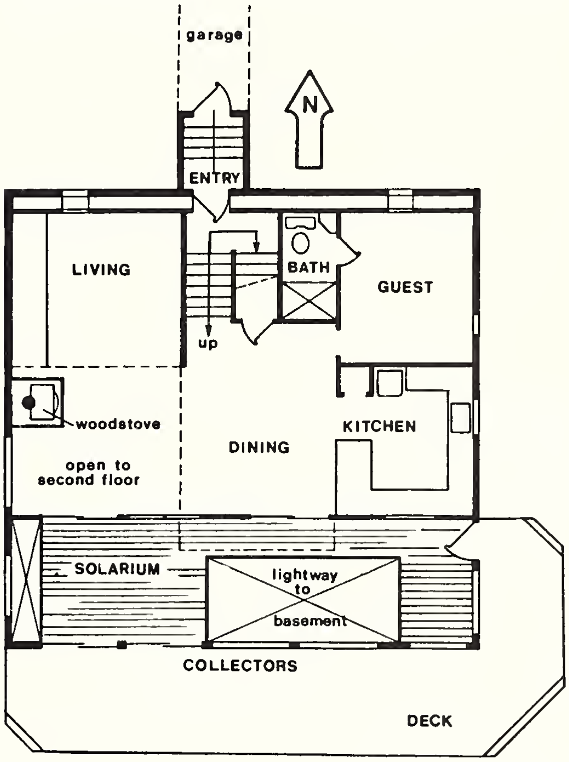
Winter temperatures on the main level of the house average between 64 ° and 68 °F in the morning. The lowest recorded morning temperature was 61 °F. Although the house was left unattended for one week in November, during which skies were cloudy and the outside temperature dipped to 6 °F, the Irons recorded a temperature of 50 °F on the main living level and 44 °F in the greenhouse when they returned. In February, when the outside temperature dropped to -25 °F, the greenhouse temperature reached a low of 34 °F.

Although the Irons are satisfied with the heating and cooling performance of their envelope house, they recommend the following changes in design and construction. All plumbing should be routed around the plenum space to ensure better convection of heat. Also, the kitchen's stove exhaust should not be ducted into the plenum; the exhaust doesn't contribute a significant amount of usable heat, although it does cause the greenhouse to harbor cooking odors. They also suggest that temperature fluctuations in the solarium could be reduced significantly by adding nighttime window insulation.

When an on-site interview was conducted on an overcast March day, the house was comfortable even though a fire had not been started for three days. The Irons' house seems well designed and constructed for energy efficiency and was built for about the same cost as a conventional house containing quality building materials.

## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 3,212 sq. ft.
**Heated floorspace:** 2,414 sq. ft.
**Window area** —
  South: 688 sq. ft.   East: 27 sq. ft.
  North: 40 sq. ft.   West: 53 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical wall; 45-degree roof
**Thermal storage:** concrete
**Auxiliary heating:** wood
**Insulation** —
  Ceiling: fiberglass to R-30
  Walls: fiberglass to R-19
  Floor: fiberglass to R-19
  Foundation: Blueboard® to R-16
  Windows: none
**Cost of materials and labor:** $85,000
**Cost per square foot:** $26
**Financing:** conventional loan
**Microclimate** —
  Degree-days: 7,437
  Average summer temperature: 65 ° F
  Average winter temperature: 36 ° F



Libby

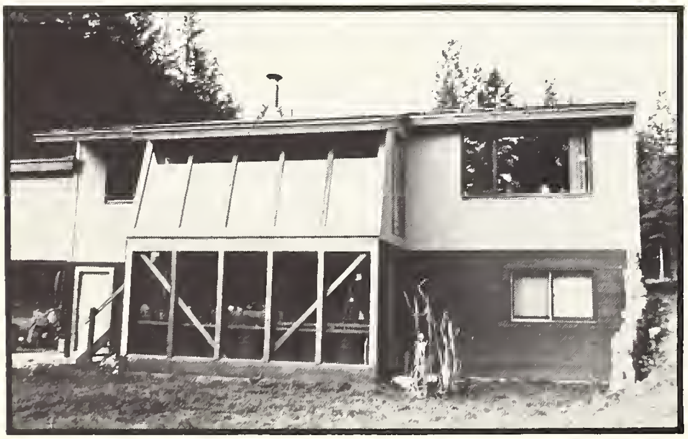
# William and Jean McCaig

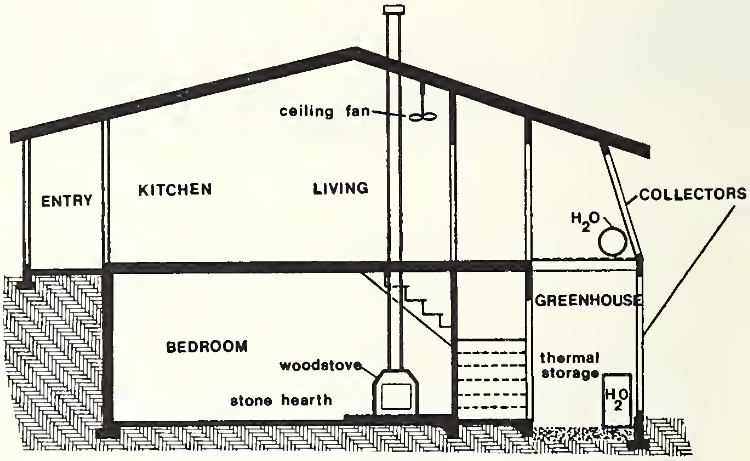
## BUILDING DESCRIPTION

This three-bedroom, split-entry house with a daylight basement is built into a wooded hill above the Kootenai River about 6 miles west of Libby. A two-story attached greenhouse on the south provides light and heat to the living room and lower-level den. Two sets of sliding glass doors on the north provide access to the kitchen. A carport and woodshed shelter the main entry on the west.

The McCaigs' foundation is built into a south-facing hillside. The north and east walls are reinforced concrete, waterproofed and insulated with 2 inches of rigid foam on the exterior. The south and west walls of the foundation are framed with 2-by-6-inch studs, insulated with 6 inches of fiberglass and sheathed with plywood siding. The 4-inch-thick concrete floor is insulated on its south and west edges with 2 inches of rigid foam, as is the exterior of the foundation wall for the attached greenhouse.

The 2-by-6-foot exterior studwalls on the upper level are insulated with 6 inches of fiberglass; a 6-mil vapor barrier covers the interior surface. The vaulted upstairs ceiling is framed with 2-by-10-inch rafters and insulated with 9 inches of fiberglass. This insulation is covered by a vapor barrier and finished with tongue-and-groove pine. A fluted metal roof overhang shades the south-facing picture windows and attached greenhouse, helping to reduce solar heat gain in the summer.





## SOLAR SYSTEM

The two-story greenhouse has a solar collection area of 243 square feet. Collected heat is stored in seven 55-gallon black barrels that support planting beds and houseplants. A slatted, cedar floor between the two levels allows air to move convectively throughout the structure.

Sliding glass doors between the greenhouse and the living space of both floors are usually left open to permit passive heating and convective airflow during the day, as well as to permit heat from a Fisher woodstove on the lower level to heat the greenhouse at night. Heat from the woodstove travels up an open stairwell into the living and dining area and can be recirculated by a ceiling fan.

## MAINTENANCE AND LIVABILITY

The home's open floorplan provides for a fairly even distribution of heat and natural lighting. The combined heat from the greenhouse and the wood stove makes the

McCaig house quite comfortable in the winter, although the bedroom in the northeast corner of the lower level doesn't receive enough heat during extremely cold periods. The McCaigs would like to redesign the east wall with a duct system to recirculate ceiling heat from the upper floor to the lower bedrooms.

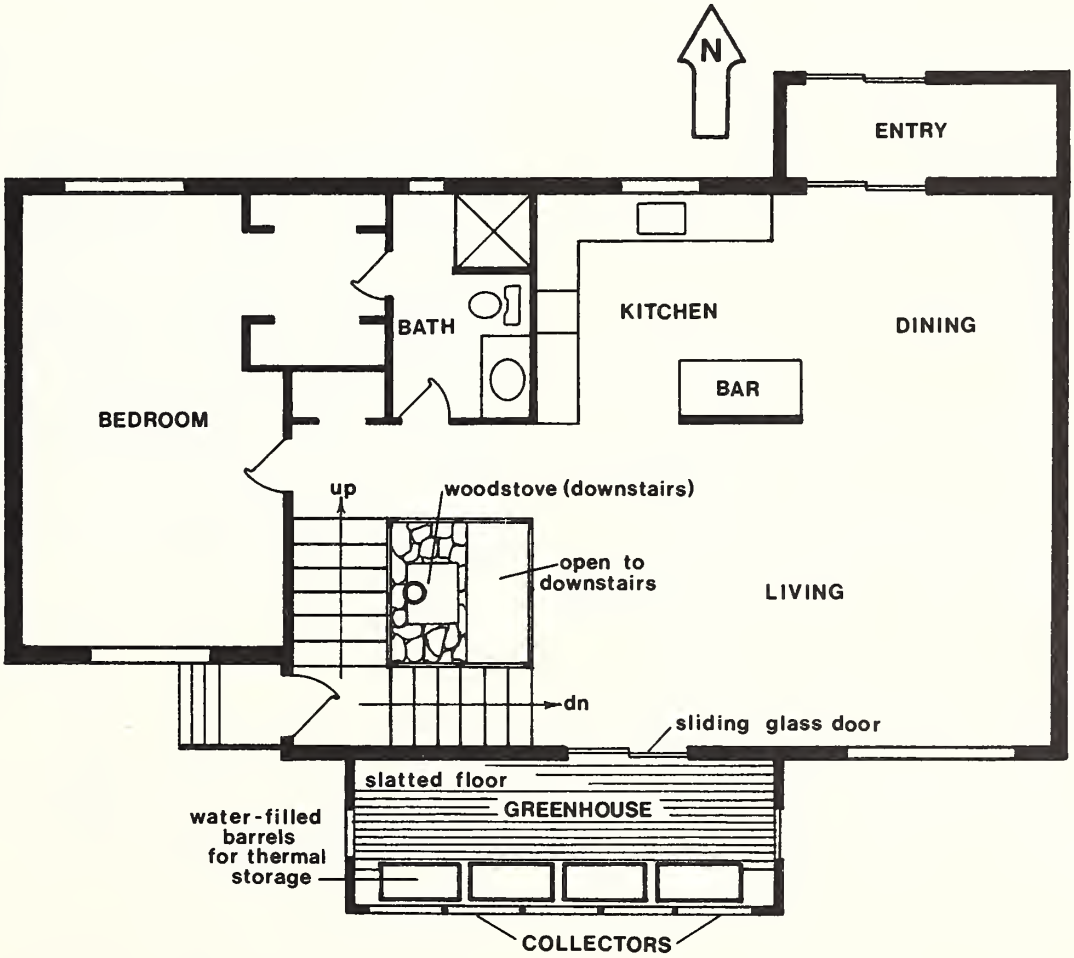
Summer cooling has not been a problem; greenhouse vents, along with doors and windows on the east and west sides of the home, provide good cross-ventilation.

Greenhouse temperatures remain fairly constant. During a cloudy day in January when the temperature outside was 29 °F, water in the heat-storage barrels remained at 62 °F. On one sunny day when the temperature outside dipped to -9 °F, the water temperature climbed to 63 °F. Auxiliary wood heat is used to prevent freezing. The greenhouse does not contain insulating curtains or shutters.

The McCaigs have added a vestibule entry and back porch to the north side of the home and would like to add an air-lock entry on the west to reduce heat loss during the winter. Nighttime insulation also would reduce temperature fluctuations in the greenhouse.

## BUILDING DETAILS

**Design type:** indirect/isolated gain
**Total floorspace:** 1,776 sq. ft.
**Heated floorspace:** 1,776 sq. ft.
**Window area** —
  South: 279 sq. ft.   East: 18 sq. ft.
  North: 70 sq. ft.   West: 10 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** 60 degrees
**Thermal storage:** water and concrete
**Auxiliary heating:** wood
**Insulation** —
  Ceiling: fiberglass to R-30
  Walls: fiberglass to R-19
  Floor: none
  Foundation: Blueboard® and fiberglass to R-16.5
  Windows: none
**Cost of materials and labor:** $64,000
**Cost per square foot:** $36
**Financing:** owner
**Microclimate** —
  Degree-days: 7,437
  Average summer temperature: 65 ° F
  Average winter temperature: 36 ° F



Polson

# Morley and Dee Cooper

## BUILDING DESCRIPTION

Built southeast of Polson in a field scattered with ponderosa pine, this two-story, wood-frame house looks out on the Mission Mountains. The Coopers' three-bedroom, two-bath home is built with post-and-beam construction. This feature, combined with a vaulted ceiling and extensive glazing on the south, creates a sense of openness. An attached garage and enclosed entryway on the north help buffer the living space from wind.

Four-foot-high concrete foundation walls provide a crawlspace under the main floor. The exterior of the concrete walls is insulated with 1½ inches of rigid foam. The 2-by-6-inch exterior frame walls are filled with 6 inches of fiberglass. A 6-mil polyethylene sheet provides a vapor barrier between the insulation and the finished interior wall. The opposing-shed roof is insulated with 12 inches of fiberglass.

## SOLAR SYSTEM

The Coopers' direct gain system collects heat through 140 square feet of south-facing windows. Heat is stored in a 350-cubic-foot stone fireplace in the living room. An attached greenhouse, planned for the southeastern corner of the house, will contribute heat through a sliding glass door. Clerestory windows provide additional light and some heat to the bedrooms on the upper level.

Solar heating is supplemented by a woodstove and a Queen Aire fireplace, both of which are vented with an outside combustion air duct. An open stairwell and several small vents between the top of the living room wall and the upper bedrooms allow a ceiling fan to circulate heated air between the floors.

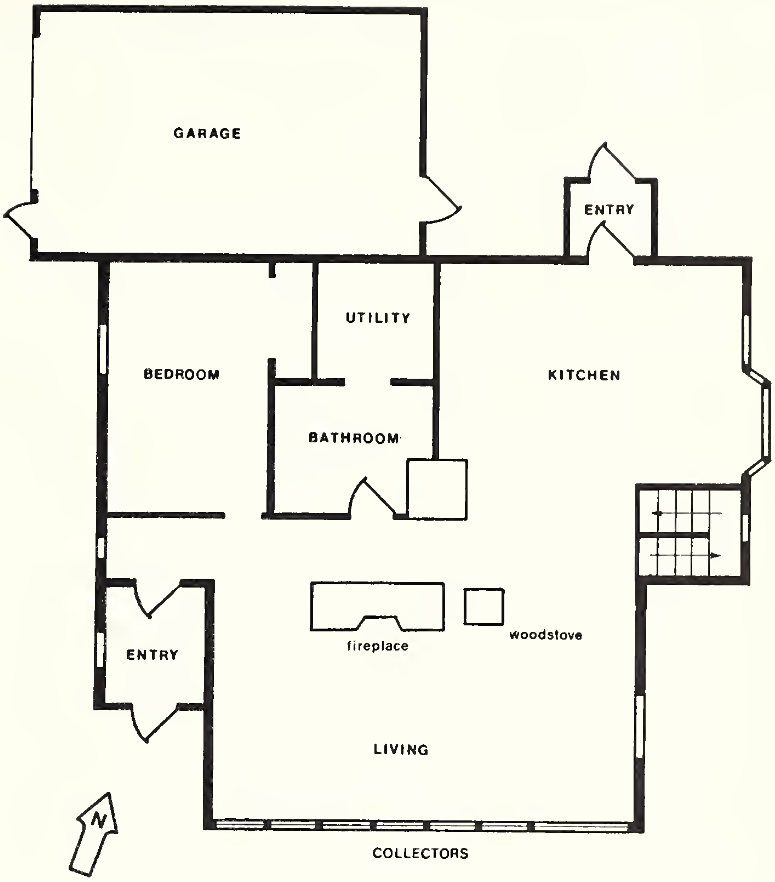
## MAINTENANCE AND LIVABILITY

Although the openness of the home's interior allows good air circulation and ample natural lighting, the high ceilings have made the lower living level more difficult to heat than anticipated. On a cloudy winter day, with the woodstove set on low, temperatures in the house range between 58 ° and 60 °F. However, when the sun is shining and the exterior temperature is 15 °F, the inside temperature will rise to 70 °F.

In the evening, the Coopers cover their south-facing windows with rigid foam panels to reduce conductive heat loss. They plan to make insulating curtains for the windows and to integrate insulated shutters into the greenhouse addition.

The woodstove and fireplace add supplemental heat to the Cooper home; during the mild winter of 1980-81, three cords of wood were burned to supplement direct solar gain. Electric baseboard heat was needed only when the house was left unoccupied for several days. A 28-inch roof overhang on the lower level and a 24-inch overhang above the clerestory windows help to block summer sunlight and prevent overheating. The clerestory windows open to aid summer cooling.

The Cooper house, which seems to be well designed and constructed, is a good example of how simple passive features can be adapted to a fairly conventional house to decrease dependence on fossil fuel.

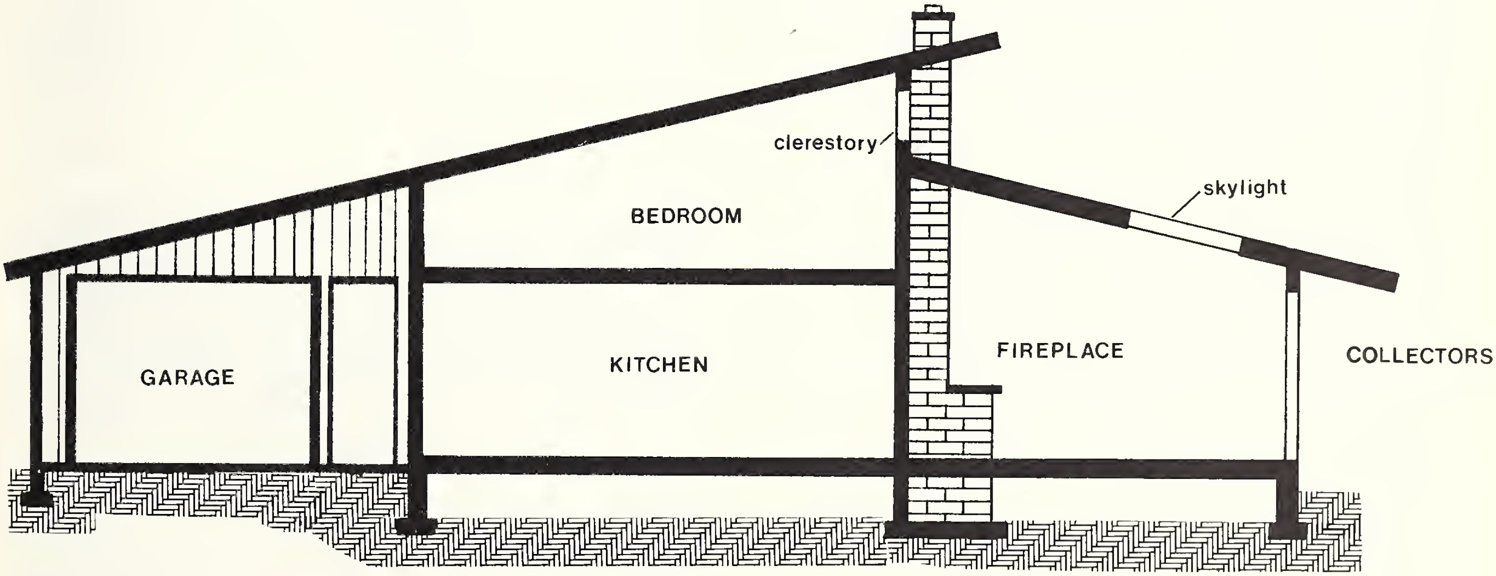


## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 2,200 sq. ft.
**Heated floorspace:** 2,200 sq. ft.
**Window area** —

| | |
|---|---|
| South: 141 sq. ft. | East: 34 sq. ft. |
| North: 11 sq. ft. | West: 61 sq. ft. |

**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal Storage:** masonry
**Auxiliary heating:** wood
**Insulation** —
  Ceiling: fiberglass to R-38
  Walls: fiberglass to R-19
  Floor: fiberglass to R-11
  Foundation: Rigid foam to R-9
  Windows: rigid foam panels
**Cost of materials and labor:** $42,000
**Cost per square foot:** $19
**Financing:** conventional loan
**Microclimate** —
  Degree-days: 7,360
  Average summer temperature: 62° F
  Average winter temperature: 37° F



Arlee

# John and Leslie Fischer/ Louis and Mary Bevier

In 1976, John Fischer received a $20,000 DNRC grant to conduct a series of solar retrofit experiments on the cabins at the Jocko Hollow Campground north of Arlee. The active systems built through this grant were discussed in Volume I of the *Montana Sunpower* series; this section deals with an indirect gain "Zomeworks wall," a direct gain, passive solar loft, and a solarium-greenhouse combination.

Since completion of these projects, the Fischers have sold the campground to Louis and Mary Bevier. The public is still welcome and encouraged to visit these projects. To arrange for a visit, contact the Beviers at Jocko Hollow Campground, Arlee, MT 59821; telephone 726-3336.

## BUILDING DESCRIPTION

Most of the solar-heated structures at the Jocko Hollow Alternative Energy Effort were designed to incorporate passive solar heating. In all remodeling projects, windows were located and built to increase passive solar gain and to prevent heat loss. At least two of the buildings include passive solar systems that can be incorporated into other building plans.

One such system is known as a Zomeworks wall, which stores passively collected heat in a wall of water-filled barrels. Such a wall was incorporated into Cabin A, which shares and contributes solar-heated water to a nearby showerhouse. A large 6-by-7-foot south-facing window was built with a double glazing of Kalwall Sun-Lite ® . Heat is stored in nine 40-gallon steel barrels that were painted black, filled with water, and stacked in front of the window. At night, exterior shutters are closed over the window to reduce heat loss. These shutters reflect additional sunlight into the window when they are open.

A passive solar loft was incorporated into an addition on another small cabin (Cabin B) at Jocko Hollow. The loft, which is a continuation of the north side of the cabin, extends above the peak of the original roof, thus creating another south-facing wall. A 3-by-5-foot window was installed on the south wall of the addition and a 3-by-4-foot window was installed on the east side. Both windows are glazed with fixed double-pane windows. A shed-like roof, sloping gently to the north side of the cabin, covers the addition. Vents with insulated covers were installed in the peak of the new roof to aid summer ventilation.

A 22-by-32-inch skylight was installed in the roof of the addition to allow more light to enter the loft and the cabin area below. To hold the heat gained through the two windows, the walls were insulated with 3½ inches of fiberglass batting, the ceiling with 6 inches. The vent covers were made by sandwiching a 1½-inch layer of rigid foam insulation between two 1-inch layers of wood.

A 220-square-foot greenhouse addition to the main house was designed to store passive solar heat in a rock Trombe wall. Part of this wall forms one wall of a wood-heated sauna. A wood stove that heats the sauna is backed into the wall. With such a design, heat from both the stove and sauna can be absorbed by the Trombe wall. Movable shutters are placed against the windows of the greenhouse to lower heat loss at night and to prevent overheating during the summer.

A foundation of concrete footings topped with 6-inch cement blocks filled with vermiculite supports the greenhouse walls. The foundation was insulated with two 1-inch layers of rigid foam, covered with a polyethylene vapor barrier, and capped with sheet metal flashing. The walls, framed with 2-by-6-inch studs, contain 6 inches of fiberglass insulation. A polyethylene vapor barrier and cedar tongue-and-groove boards complete the inside of the upper walls. The exterior surface of the wall is covered with two layers of ½-inch Celetex® insulation and shiplap spruce boards.

The insulated floor was constructed by first covering the ground with a layer of gravel and a 6-mil polyethylene vapor barrier. Two layers of 1-inch-thick rigid foam insulation then were placed and covered with another polyethylene vapor barrier. Sand and flat stone subsequently were added to form the floor surface.

Triple-glazed windows were placed in the upper walls. Additional windows were made with two layers of regular-grade Kalwall fiberglass. A ¾-inch airspace separates the layers. Interior insulated shutters were built to cover the windows. The shutters, made from 5/8-inch plywood and expanded polystyrene, were placed on the windows by hand.

## SOLAR SYSTEM

The rock Trombe wall was built with 4-inch cement blocks on the interior or sauna side and 6-inch blocks on the greenhouse side. An 8-inch space between the two walls was filled with 1-to-1½-inch washed rock for extra storage mass. The greenhouse wall was faced with dark natural stone.

To allow the Trombe wall to absorb as much heat as possible from the integrated wood stove, the stove's exhaust pipe was divided into two separate 4-inch pipes, which extend through a wide area of the wall before joining the chimney pipe near the top of the wall. When the greenhouse temperature is above that of the house, a circulation fan can be turned on to move heat from the greenhouse into the living space.

## MAINTENANCE AND LIVABILITY

The precise space heating contribution of the Zomeworks wall in Cabin A has not been calculated. Nevertheless, by converting to a simple barrel wood stove and constructing the passive storage wall, the project saved the owners an estimated $150 in annual utility costs.

Since Cabin B is heated with wood, the only savings garnered by adding the passive solar loft would be represented in wood not burned. Thus, the financial savings are not great. In terms of building design, however, the loft makes an important contribution. It lets in more natural light, thereby reducing the amount of electricity needed to light the cabin. It also provides additional space for preheating domestic hot water (see Volume I), and increases space for sleeping and storage.

Greenhouse temperatures have never dropped below 42°F. On winter nights during subzero weather, the backup stove has produced enough heat to keep greenhouse temperatures at an acceptable level. Because the site is well protected from the wind and because the structure incorporates many conservation features, the greenhouse has performed well. The cedar walls, coated with moisture sealant, have held up well despite the condensation that forms on them as temperatures fluctuate within the greenhouse.

No major problems were encountered while constructing the Jocko Hollow passive solar projects. The minor problems that did occur stemmed mostly from overdesign. Fischer had planned to install a hot water heating coil from the home's main wood stove to provide supplemental heat to the greenhouse in winter. He also had planned to build both an internal manual shutter system and an exterior hydraulic shutter system to reduce heat loss. Early operations, however, indicated that neither system would be needed.

### BUILDING DETAILS

Greenhouse

**Design type:** indirect gain
**Total floorspace:** 220 sq. ft.
**Window area** —
  South: 50 sq. ft.   East: 28 sq. ft.
  North: 0   West: 0
**Glazing:** three layers of glass
**Glazing orientation:** south and east
**Glazing angle:** 60 degrees
**Thermal storage:** rock
**Auxiliary heating:** wood
**Insulation** —
  Ceiling: fiberglass to R-19
  Walls: fiberglass to R-19
  Floor: rigid foam to R-11
  Foundation: rigid foam to R-11
  Windows: none
**Cost of materials and labor:** $3,877
**Cost per square foot:** $17.62
**Financing:** DNRC grant (partial)

Frenchtown

# Dennis and Karen Workman

## BUILDING DESCRIPTION

The Workmans live in a three-bedroom, underground passive home overlooking the Clark Fork valley just north of Frenchtown. The home's living area opens to a 340-square-foot greenhouse that extends the entire length of the south wall. This single-level, concrete structure is buffered on the north by an enclosed entryway and an attached garage and shop. The home's bedrooms, baths, utility room, and sauna are located on the north wall; all are naturally lighted through openings in the concrete wall between the living area and the bedrooms. Four clerestory windows, stepped to the south, allow daylight to enter the garage and shop.

The home's 6-inch concrete slab floor is separated from the earth by a 6-mil layer of polyethylene and 1 inch of polystyrene beadboard. One inch of polyurethane foam covers the exterior of the reinforced-concrete walls from the foundation footings to a point 4 feet below the roof line. Above that point the foam is 2 inches thick. The roof, consisting of 1-foot-thick, prestressed, hollow-core concrete panels, is insulated on the outside with 2 inches of urethane foam and 2 feet of earth. These concrete roof panels, welded and grouted together, form a strong and effective roof. Six-mil polyethylene sheeting and asphalt emulsion on the concrete waterproof the structure. The east and west walls of the house are bermed with 14 feet of earth.

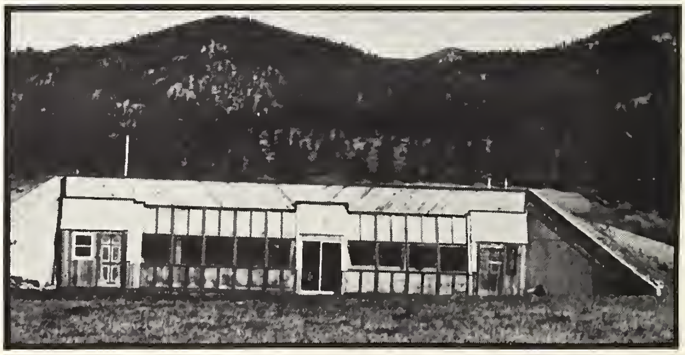
## SOLAR SYSTEM

The home's concrete walls and floor store solar heat gained directly through 508 square feet of greenhouse glazing. The greenhouse opens to a kitchen, dining room, and sunken living room, allowing heat to be collected and stored in an uninterrupted living space. To reduce heat loss and increase thermal mass, the greenhouse was insulated to a depth of 4 feet and refilled with soil. Planting beds store additional heat. The Workmans plan to install insulating shutters over the double-glazed Kalwall fiberglass-and-glass greenhouse to reduce heat loss on winter nights and to prevent overheating in the summer.

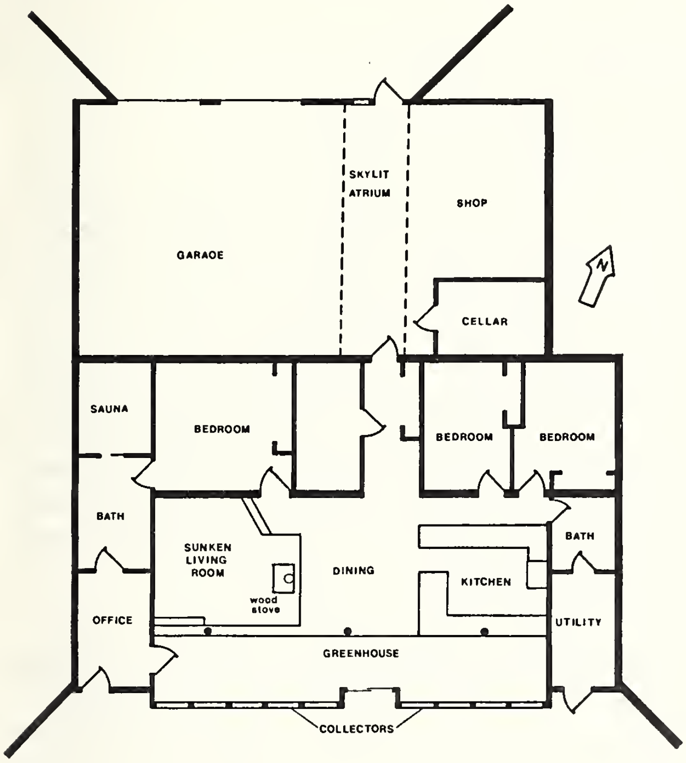
## MAINTENANCE AND LIVABILITY

Although the Workmans have been living in the house since May 1980, it wasn't completely enclosed until July of that year. Despite the lack of an overhanging roof on the south, the Workmans experienced no problems with overheating during that first summer. Also, although winter temperatures have been cool at times, house temperatures generally range between 63° and 68°F on cloudy winter days when no backup heating is used. On sunny winter days, temperatures of 80°F have been recorded. A wood stove provides backup heating.

The Workmans are completely satisfied with their underground home and the performance of their passive heating scheme. Nevertheless, they suggested the following methods for overcoming some minor problems: Since most of the building is concrete, finding an experienced concrete contractor to build this type of home is imperative. The Workmans found it necessary to level the roof panels with blocking because the bearing walls they installed themselves were finished irregularly. Also, because much of the home's plumbing is buried beneath the cement floors, access for repairs is difficult. Wood floors would solve this problem, although they also would decrease available heat storage mass.

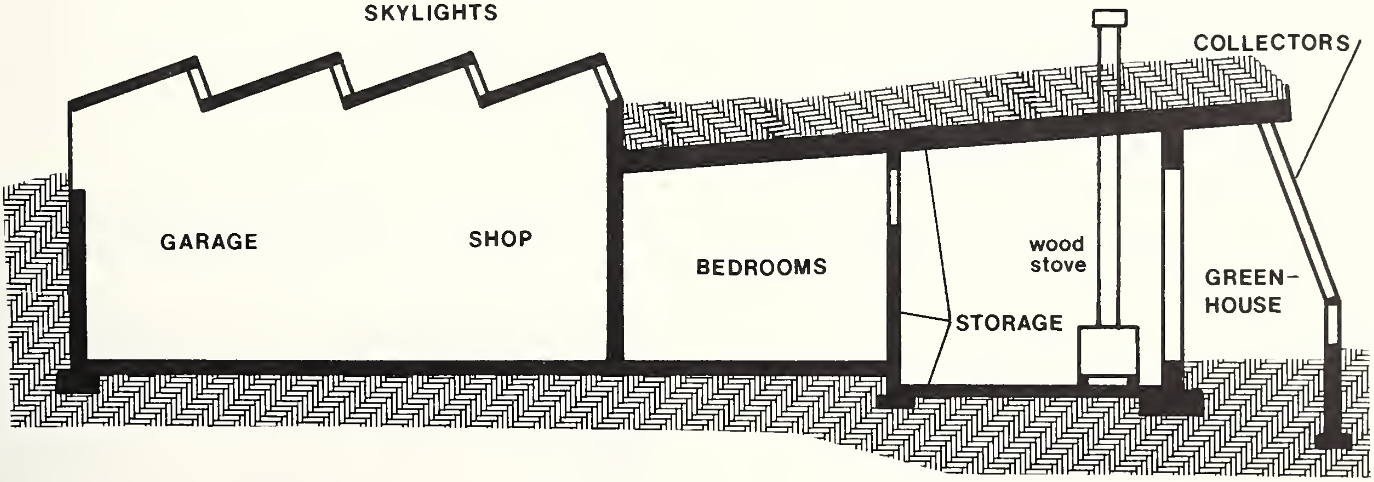


The owners experienced problems when condensation formed between the two layers of glass in their homemade, fixed windows. These problems could be solved by placing a desiccant between the panes before sealing them with butyl caulk, or by installing commercially manufactured double-glazed windows.



## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 3,293 sq. ft.
**Heated floorspace:** 1,800 sq. ft.
**Window area** —
  South: 508 sq. ft.  East: 0
  North: 45 sq. ft.  West: 0
**Glazing:** two layers of glass
**Glazing orientation:** 15 degrees east of south
**Glazing angle:** vertical
**Thermal storage:** masonry
**Auxiliary heating:** wood
**Insulation** —
  Ceiling: urethane foam to R-14
  Walls: urethane foam to R-14
  Floor: beadboard to R-4
  Foundation: urethane foam to R-7
  Windows: none
**Cost of materials and labor:** $84,600
**Cost per square foot:** $26
**Financing:** owner
**Microclimate** —
  **Degree-days:** 7,931
  **Average summer temperature:** 63° F
  Average winter temperature: 35° F



**Missoula**

# John Means

John Means received an $8,600 grant from DNRC's Renewable Energy Program in August 1978. The project was unique in its attempt to integrate a Trombe wall with a solar greenhouse built largely underground. The public is encouraged to visit the Means' home in Pattee Canyon, southeast of Missoula. For information, contact Means at 2870 Solterra Lane, Missoula, MT 59801; telephone 549-2126 or 243-4003.

## BUILDING DESCRIPTION

Although most solar homes face south, the Means' home sits on a gentle, north-facing slope. The north and south sides of the two-story, 2,200-square-foot home are exposed, while the east and west sides are bermed and the roof is covered with earth and sod. The north side features an upper and a lower entryway containing three round windows. The exposed south end, wider than the north, is almost entirely glazed with large clerestory windows and a greenhouse.

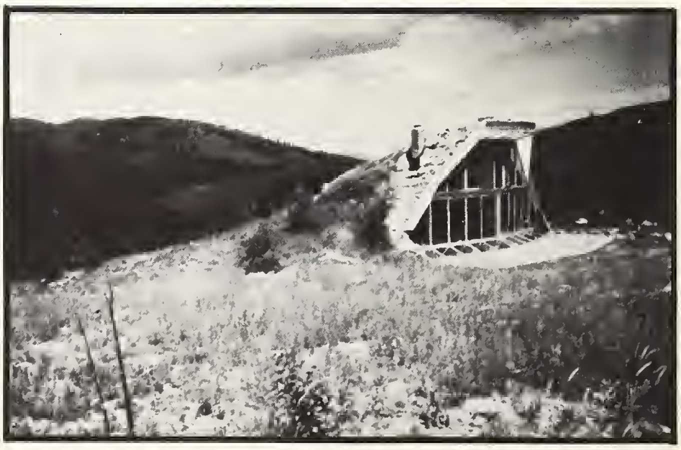
To provide both structural support and a thermal storage mass, 12-inch-thick concrete was used for the floor, walls, and roof of the home. To retain heat in the concrete, the exterior surfaces of the floor and walls were insulated with a 1-inch layer of rigid, waterproof polystyrene. The insulation beneath the floor rests on a 2-inch layer of gravel that prevents moisture from seeping into the insulation. To increase structural strength, the walls and floor were reinforced with steel rebar.

A concrete-like material known as Gunite® was used to construct the roof. Gunite® was chosen because it drys about four times faster than regular concrete, and because it can be applied quickly, thereby reducing labor costs and slumping of the walls. The roof was constructed by laying 2-by-6-inch tongue-and-groove pine on the edges of inverted steel I-beams. Next, the wood was covered with a layer of tar paper, and steel rebar was carefully placed for structural support. Gunite® then was applied under 100 pounds per square inch of pressure from a spray nozzle. Finally, 3½ inches of urethane foam insulation, with an R-25 insulating value, was sprayed onto the concrete. To prevent moisture from accumulating in the urethane, a plastic sealer known as Elastrocreel® and a layer of Visqueen® were spread on the insulation. Wooden racks were attached to hold the earth to the roof.

The completed roof, engineered to withstand at least 600 pounds per square foot of pressure, was covered with clay and rocky soil to depths of up to 2 feet, depending on the drainage demands of the different portions of the roof. Topsoil, 2 to 3 inches thick, was spread on the earthen layer for seeding with grass. Sections of sod were placed on those areas of the roof considered particularly prone to erosion.

## SOLAR SYSTEM

A bank of double-glazed clerestory windows covering the exposed south area of the house allows sunlight to fall on a two-story Trombe wall and into an atrium or submerged greenhouse area. The greenhouse, which gains heat directly from the sun or from warm air flowing through an airspace behind the Trombe wall, is used for growing plants as well as for providing natural light and heat to adjoining bedrooms. An automated, insulative curtain manufactured by Thermotech, Inc. reduces heat loss through the clerestory windows.



The Trombe wall, composed of 18-inch-thick concrete, is 42 feet long and 17 feet high, rising from a concrete footing beneath the floor and extending into the second story or main floor of the home. Aluminum irrigation pipes filled with water were embedded at 1-foot intervals throughout the wall. While the water pipes add about 4 hours of heat-storing capacity to the wall, their primary purpose is to conduct heat evenly through the wall. Such conduction is important because the sun strikes different parts of the wall at different times of the year and because storage efficiency depends on the distribution of heat through the wall. The pipes, which extend above the top of the storage wall near the ceiling, are refilled once a year. Because they are open at the top, the pipes also humidify the home.

The upper portion of the Trombe wall forms one wall of the living room. This section was covered with natural stone and contains a small fireplace. About one-third of the collection window area extends above the top of the wall so that the upper floor can gain solar heat directly. The windows are shielded from excessive summer sun by a section of overhanging roof. A ¾-inch copper coil in the south surface of the concrete wall preheats water for domestic use.

The house is designed to take full advantage of natural heat convection. The kitchen, dining, and daytime living areas are upstairs, while four bedrooms, the greenhouse area, two bathrooms, and a recreation room are on the lower floor. Efficient wood-burning stoves were installed on both floors for backup space heating. Another wood stove in the kitchen also contributes heat.

In the Means' system, air rises between the south-facing windows and the solar-heated surface of the Trombe wall. Because the surrounding earth is cool, a significant temperature differential usually exists between the ground floor and the ceiling; this differential causes a relatively rapid flow of air to the top of the Trombe wall. In passing over the wall, the air strips additional heat from the water storage pipes as it fills the upper floor space. As the upper level fills with heated air, cooler air is forced back down to the lower level through ducts along the perimeter of the floor.

## MAINTENANCE AND LIVABILITY

Before the insulating curtain was installed, the Trombe wall had been relatively ineffective in winter. When outside temperatures dropped below 20 °F, most of the wall's usable heat was lost, making it necessary to use the wood stove during the day. Still, the Trombe wall and the concrete walls, floors, and ceilings seem to work well as a heat-storage medium. During one exceptionally sunny five-day period in January 1980, when outside temperatures averaged about 0 °F, the daytime temperature on the home's upper floor remained between 72 ° and 75 °F without backup heating. The wood stove was used only at night during this period. The concrete thermal mass also seems to moderate temperatures well, since upstairs temperatures have never exceeded 78 °F for more than an hour.

Whether solar heat or wood stove heat is being used, a temperature difference of 3 ° to 10 °F persists between the two floors of the house. This implies that cooler air is forced from the upper story and circulated for reheating on the lower floor, as was intended in the system's design. Means believes the system is meeting or exceeding its predicted solar heating fraction of 80 percent.

Because the passive solar heating features are so closely integrated with the structure itself, the real cost of the solar investment is probably less than the approximately $15,000 spent on materials for the specific solar components. With a cost per square foot comparable to that of a conventional home, the Means' earth-sheltered design with passive solar heating seems to be economically sound.

Design calculations for this project predicted a monthly savings of $60 at current electricity rates. Actual performance in the first year showed that the only fuel cost for space heating was the price of about 3½ cords of wood. Assuming that the interest or discount rate on the investment would be nearly cancelled out by savings over projected utility rate increases, Means calculated that the payback period for the solar investment would be about 15 years. If further modifications improve performance as expected, this 15-year payback period should be met or reduced.

The economic picture for the Means home is improved by the domestic hot water preheating setup. Although the heat exchange coils cost only $47, they supply heat worth about $5 at current electricity rates each month. Also, the greenhouse area could be used to grow food, which would represent an extra economic benefit.

### BUILDING DETAILS

**Design type:** indirect gain
**Total floorspace:** 2,200 sq. ft.
**Heated floorspace:** 2,200 sq. ft.
**Window area** —
  South: 400 sq. ft.  East: 0
  North: 62 sq. ft.  West: 0
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** concrete and water
**Auxiliary heating:** wood
**Insulation** —
  Roof: urethane foam to R-25
  Walls: rigid foam to R-5.5
  Floor: rigid foam to R-5.5
  Foundation: rigid foam to R-5.5
  Windows: insulating curtains
**Cost of materials and labor:** $15,500 (solar portion)
**Cost per square foot:** $42
**Financing:** DNRC grant ($8,600)
**Microclimate** —
  Degree-days: 7,931
  Average summer temperature: 65 ° F
  Average winter temperature: 26 ° F

Missoula

# Bettina Delaney

## BUILDING DESCRIPTION

This two-story passive solar home sits on the southwest shoulder of Mount Sentinel in Missoula. A large, two-story greenhouse, integrated into the foundation and roof line, comprises most of the home's south side. Heat collected through the south glazing is stored in a masonry wall. A vestibule entry on the north is protected from the wind and cold by an attached garage. An entryway on the lower level provides access to the family room, bedrooms, utility room, and bath.

The lower level has 8-inch-thick poured concrete exterior walls. These walls are insulated with 2 inches of Thermax® on the waterproofed, outside surface of the concrete. The inside surface of the concrete walls was furred out with 2-by-4-inch studs, insulated with 3 ½ inches of fiberglass, and covered with sheetrock. The lower-level floor is 4-inch-thick poured concrete, which provides additional structural support for the large masonry-block hearths on both levels.

The second story features conventional 2-by-4-inch exterior studwalls. These walls were filled with 3½ inches of fiberglass, sheathed on the outside with 1 inch of Thermax®, and sided with channel cedar boards. Corrugated Thermax® vent strips allow any moisture that gets past the vapor barrier to travel upward toward the top plate of the wall and escape through an airspace designed in the rafters. A cathedral ceiling opens to the greenhouse, living room, and dining room. A squirrel-cage fan in the ceiling recirculates heated air and prevents thermal stratification.

## SOLAR SYSTEM

The first floor of the Delaney house is similar to a daylight basement. The north wall is set into the hillside below grade, while the glass south wall is above grade. The foundation wall is 7 feet high on the uphill or north side, and 4 feet high on the downhill or south side, to allow more room for glazing. The exterior foundation surface is sheathed with 2 inches of Thermax®.

The upstairs master bedroom and bath are set on a short footing wall, which elevates the floor of these rooms to form a crawlspace beneath them. The floor is insulated with fiberglass.

An oversized concrete footing supports a 12-foot-high, concrete-filled, masonry-block common wall between the house and the greenhouse. The side of the wall facing the greenhouse is painted flat black to absorb solar heat. French doors and windows on the lower level of this wall allow air and heat to exchange between the greenhouse and the living space. Exposed planting beds filled with soil cover most of the greenhouse floor.

The kitchen, bedrooms, and bath have 7-foot ceilings, which help to keep the warmer air closer to the most commonly used areas. This lowered ceiling is well insulated with blown-in fiberglass. In the cathedral ceiling over the dining and living rooms, special steps were taken to provide ventilation through the rafters. A 2-inch airspace between the fiberglass and the roof sheeting is vented by a continuous soffit and a ridge vent. Constructing the roof with T.J.I.® truss joists allowed 12 inches of fiberglass insulation to be installed in the ceiling. The ceiling and exterior walls contain a 6-mil polyethylene vapor barrier. All outside doors were sealed with a high-quality vinyl weatherstripping.

Special care was taken when designing the home to ensure that the floorplan would allow adequate cross-ventilation during the summer. The windows are located to capture the cooling breezes that move up the valley, and a 4-foot roof overhang helps shield the south windows from the hot summer sun.

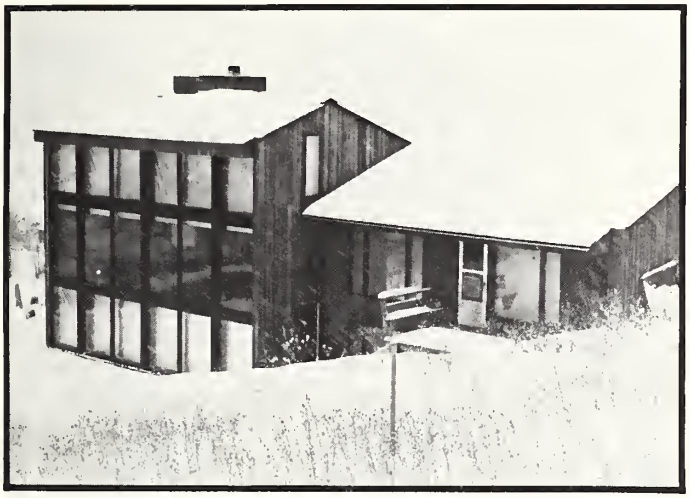
Self-inflating, movable, insulative curtains cover both the upper and lower tiers of fixed south windows. These curtains, rated at R-9, are mounted on large electrically operated rollers that raise or lower the curtains as needed. Each curtain consists of four aluminized mylar sheets that unroll to allow air to enter the spaces between the sheets. A good seal between the edge of the curtain and the window frame helps to prevent heat loss. Verasol® aluminum-faced, fabric shutters prevent heat loss from the remaining windows in the house.

## MAINTENANCE AND LIVABILITY

Delaney is satisfied with the way passive solar heat is distributed throughout the house and its contribution to the home's low monthly utility bills. During the winter of 1981-82, the highest utility bill for the home was less than $40, including electricity. A gas furnace, used to heat water for backup space heating, has been used only occasionally.

Condensation has not been a problem in the greenhouse, which heats up measurably on sunny winter days. Also, the thermal curtains have prevented the enormous evening heat losses commonly experienced in passive solar homes with uninsulated windows.

According to the owner, the house is comfortable year round and the feeling of openness inspired by the passive solar design makes the house seem larger than it really is.



### BUILDING DETAILS

**Design Type:** indirect gain
**Total Floorspace:** 2,888 sq. ft.
**Heated Floorspace:** 2,500 sq. ft.
**Window area** —
  South: 541 sq. ft.  East: 22 sq. ft.
  North: 52 sq. ft.  West: 60 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal Storage:** masonry
**Auxiliary heating:** gas-fired boiler; wood
**Insulation** —
  Ceiling: fiberglass to R-38
  Walls: Thermax® and fiberglass to R-21
  Floor: none
  Foundation: Thermax® to R-30
  Windows: insulating curtains and shutters
**Cost of materials and labor:** $90,000
**Cost per square foot:** $31
**Financing:** owner
**Microclimate** —
  Degree-days: 7,931
  Average summer temperature: 65 ° F
  Average winter temperature: 26 ° F

Greenough

# Richard and Jean Goldsmith

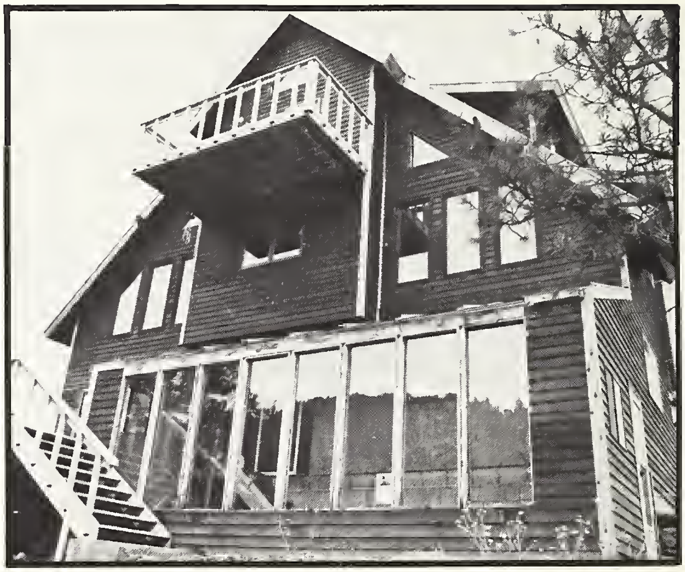
## BUILDING DESCRIPTION

The Goldsmith house overlooks the Blackfoot River about 30 miles east of Missoula. This three-story, three-bedroom house receives most of its heat from an attached greenhouse and extensive glazing on the south. An attached garage and vestibule entry on the north side of the home buffer the kitchen, dining room, and living room from cold winter winds. The open, vaulted ceiling on the south, which rises to the third-floor master bedroom, allows heat to flow from the main floor to the upper levels. South-facing, sliding glass doors on the first and third levels provide access to outdoor decks and increase the total solar collection area.

Standard 8-inch-thick concrete walls form the foundation, which was insulated on the outside with 2 inches of molded polystyrene and covered with 4-mil polyethylene plastic before back-filling. The conventional 2-by-4-inch studwall is filled with 3½ inches of Thermo-Con®, a wet-spray cellulose. Gable and dormer roofs on the east and west sides of the home were insulated with 6 inches of fiberglass and sheathed on the inside with 2 inches of Thermax®. Furring strips, nailed through the Thermax® onto 2-by-8-inch rafters, provided a surface for installing tongue-and-groove ceiling boards.

## SOLAR SYSTEM

An attached greenhouse and 214 square feet of double glazing on the south provide the solar collection surface for this 1,600-square-foot home. Heat is stored in the brick floor of the greenhouse and in the partially exposed foundation wall of the house, which also serves as the back wall of the greenhouse. Heat collected in the 240-square-foot greenhouse passes into the kitchen and living room through casement windows and a sliding glass door. Warm air enters the top two floors through interior windows opening to the living room below. These windows can be opened and closed to control the temperature in the upper rooms.



Solar heating is supplemented by an Itasca forced-air wood furnace in the basement. Heat ducts lead from the stove to registers on the main floor. The Goldsmiths rely on natural convection and the interior windows on the second and third floors to distribute this auxiliary heat.

Passive cooling of this house is enhanced by east-west windows in the greenhouse that open to take advantage of summer breezes along the river. Four 1-foot-square ceiling vents in the greenhouse also open to exhaust excess hot air. East-west windows in the house open to further promote summer cooling.

## MAINTENANCE AND LIVABILITY

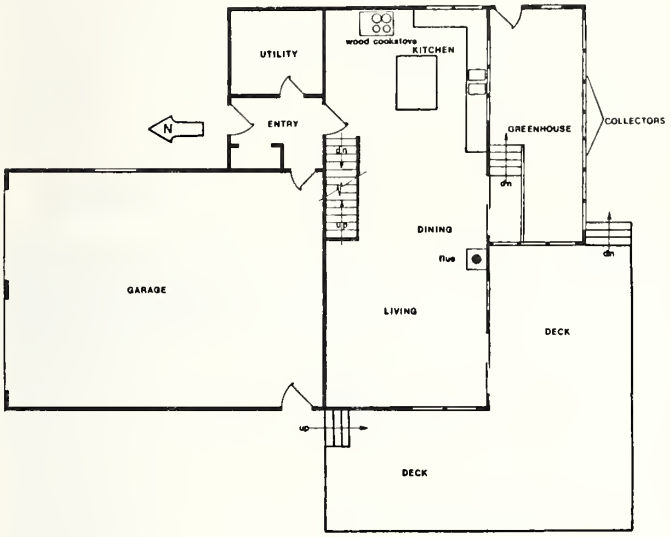
The Goldsmiths are satisfied with their passive solar system. Winter temperatures fluctuate between 63 °F in the morning and 73 °F after a sunny day. The house, if left unattended for several days, reaches a low of about 50 °F. Lighting a small fire in the wood furnace in the morning keeps the home warm for the remainder of the day. The home's open floorplan and multistoried design permit good airflow and even heating in the structure.

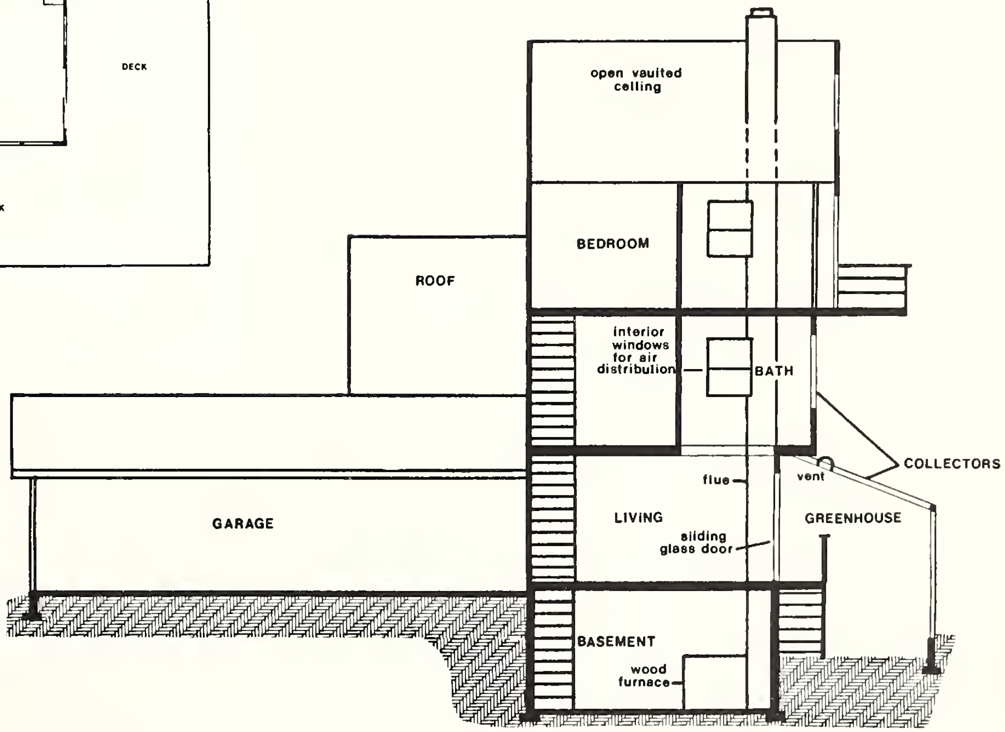
To improve the performance of their passive design, the Goldsmiths would increase thermal storage with an insulated slab floor in the greenhouse and living room, and with a larger masonry storage wall in the back of the greenhouse. They also would extend the greenhouse to cover the entire south side of the house. In addition, they would replace the home's 2-by-4-inch framed exterior studwall with a 2-by-6-inch framed wall and increase the amount of wall insulation with an exterior rigid foam sheathing.

Although their home cost no more to build than a conventional home of the same size, the Goldsmiths believe it is more comfortable that their previous conventional homes. They attribute the home's increased comfort level to added insulation, its tiered floorplan, and the passive heating aspects of its design.

## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 1,840 sq. ft.
**Heated floorspace:** 1,600 sq. ft.
**Window area** —
  South: 428 sq. ft. East: 42 sq. ft.
  North: 11 sq. ft. West: 52 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** 5 degrees west of south
**Glazing angle:** vertical
**Thermal storage:** concrete and brick
**Auxiliary heating:** wood
**Insulation** —
  Ceiling: Thermax® and fiberglass to R-28
  Walls: cellulose to R-19
  Floor: none
  Foundation: rigid foam to R-7
  Windows: none
**Cost of materials and labor:** $50,000
**Cost per square foot:** $27
**Financing:** owner





Stevensville

# Paul and Irva Vandiver

## BUILDING DESCRIPTION

Set on 9 acres overlooking the Bitterroot River, this two-bedroom, wood-frame house is sited to take advantage of a good southern exposure. The passive solar house incorporates two Trombe walls and an attached greenhouse to collect and store heat. The home's open floorplan allows good distribution of natural light and heat. A balcony provides a walkway between two work areas in the upstairs loft, which is illuminated by a clerestory along the full length of the house.

The 2-by-6-inch exterior walls stand on an 8-inch-thick, reinforced concrete foundation, insulated on the outside with 1 inch of Styrofoam Blueboard® . Oversized footings support the two concrete Trombe walls. The opposing-shed roof was constructed with exposed 2-by-12-inch rafters and decked with 2-by-6-inch tongue-and-groove pine. The Trombe wall in the living room provides bearing for the south shed roof rafters. The roof was insulated with 1 inch of Styrofoam Blueboard® and covered with 90-pound mineral roll roofing.

## SOLAR SYSTEM

This indirect gain system employs two masonry Trombe walls and an integrated greenhouse to passively heat the Vandivers' house. The Trombe wall in the living room measures 36 feet by 8 feet by 16 inches and is heated through 288 square feet of double Kalwall glazing. A series of eight vents in the base of the Trombe wall and an equal number in the top of the wall allow convective circulation of warm air from the space next to the glazing into the living room. The vents at the base of the wall can be closed manually at night to prevent back-drafting. The interior surface of the glazing is covered at night with Window Quilt ® to reduce heat loss.

A 12-by-8-foot Trombe wall forms a common wall between the 96-square-foot greenhouse and the kitchen. The greenhouse floor is filled with 2 feet of washed gravel. Four-inch perforated plastic pipe, buried in the gravel, is connected to a small fan that pulls warm air from the upper loft of the house and forces it through the buried pipe, warming the gravel in the greenhouse. A sliding glass door separating the greenhouse from the dining room can be opened to permit heat exchange between the two areas. A fan in the vaulted ceiling helps recirculate rising warm air through the lower level of the house.

The south windows are shaded during the summer by 30-inch overhangs on both levels of the opposing-shed roof. The greenhouse is cooled through roof vents that operate either manually or automatically. The automatic venting mechanism consists of a wax-filled cylinder containing a piston that opens the vent as the heated wax expands. A west-facing door on the greenhouse can be opened to further increase ventilation.

## MAINTENANCE AND LIVABILITY

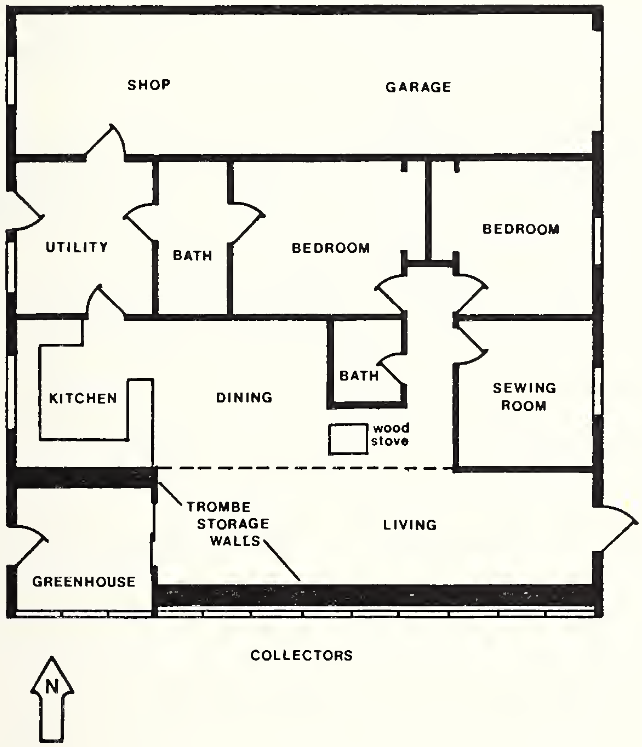
A garage and storage room on the north side of the house buffer the living space from cold and wind. Although the north wall already contains 6 inches of fiberglass insulation, Vandiver plans to berm it with earth to insulate the home even more. Adding insulation to the roof before it is covered with earth also should help reduce heat loss through the ceiling.

Temperatures throughout the house remain fairly constant, although the north bedrooms usually are not as warm as the living space directly behind the Trombe walls. When the sun shines, the open living area of the house heats evenly and backup heating by a wood stove is not necessary. However, because temperatures inside the home have dropped to 50 °F during the winter, two cords of wood generally are needed for auxiliary heating.

Summer cooling has not been a problem, since the Window Quilt® thermal curtains and the overhangs help to cut out direct sunlight and because casement windows in the clerestory open for ventilation.

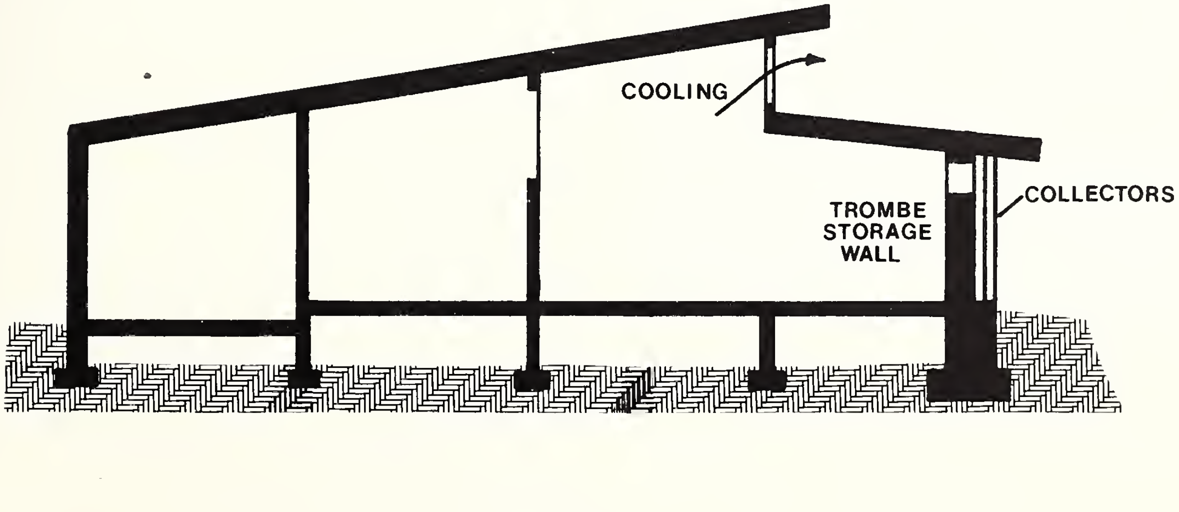
Natural lighting, reduced by placing the Trombe wall just inside the southern glazing, is regained through the clerestory windows and openings at the top of the partitions between the living room and the bedrooms. A combined sewing room and study loft above the living area receives a great deal of natural light and is heated directly through the clerestory windows.

The Vandivers have experienced a minor problem with condensation, which collects between the layers of Kalwall glazing in front of the Trombe wall. This problem could be alleviated by paying closer attention to sealing out moisture while constructing the windows.



### BUILDING DETAILS

**Design type:** direct/indirect/isolated gain
**Total floorspace:** 2,304 sq. ft.
**Heated fdoorspace:** 1,728 sq. ft.
**Window area —**
South: 432 sq. ft.   East: 0
North: 0   West: 43 sq. ft.
**Glazing:** two layers of glass and fiberglass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** concrete
**Auxiliary heating:** wood, electric baseboard
**Insulation —**
Ceiling: Blueboard® to R-5.5; 90 lb. mineral roll roofing
Walls: fiberglass to R-19
Floor: none
Foundation: Blueboard® to R-5.5
Windows: Window Quilt®
**Cost of materials and labor:** $55,000
**Cost per square foot:** $24
**Financing:** owner
**Microclimate —**
Degree-days: 7,187
Average summer temperature: 63 ° F
Average winter temperature: 35 ° F



Darby

# Ed and Veryl Kosteczko

## BUILDING DESCRIPTION

The east slope of the southern Bitterroot range receives slightly more sunshine than the rest of western Montana. The Kosteczkos have taken advantage of this fact by incorporating both water and stone heat-storage walls and an attached greenhouse into their home.

Located on a flat, grassy bench just west of Darby, the Kosteczko home looks conventional. This single-level, three-bedroom house with an attached garage sits on a masonry-block foundation, insulated on the exterior with 2 inches of molded polystyrene panels and flashed with aluminum above grade. The spaces in the masonry block are filled with vermiculite, and the outside of the wall is waterproofed with asphalt emulsion. The north and east walls are framed with 2-by-6-inch studs and filled with 6 inches of fiberglass, while the west and south walls are framed with 2-by-4-inch studs and filled with 3½ inches of fiberglass. A 4-mil vapor barrier lines the insulation on the ceiling and exterior walls. The scissors-truss roof is insulated with 12 inches of fiberglass over the vaulted ceiling space; 12 inches of cellulose insulates the lowered ceiling throughout the rest of the house.

## SOLAR SYSTEM

The attached greenhouse, architecturally integrated into the roof line of the house, is glazed with 100 square feet of Thermopane® windows on the south-facing vertical wall and double-layered Kalwall fiberglass on the roof. The greenhouse sits on a 4-foot-high foundation of masonry block, filled with vermiculite, sheathed on the exterior with 1 inch of Thermax® , and covered with dark native stone. East and west doors open for summer ventilation. A sliding glass door allows heated air from the greenhouse to reach the living space in the winter.

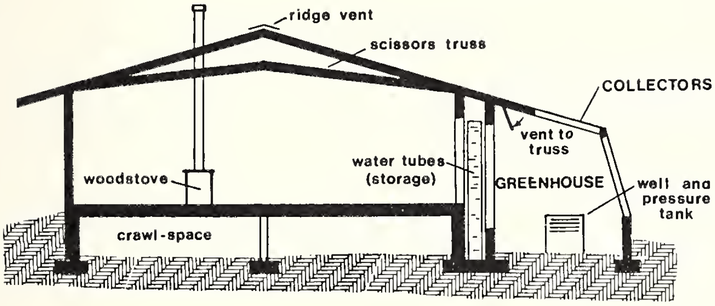
The interior of the greenhouse foundation was backfilled with gravel. A small pit in the center of the greenhouse floor houses a pressure tank for the water system, as well as an electric water heater. With this design, cold incoming well water can be preheated by the warm air in the greenhouse before it is pumped into the home's electric hot water heater. Six inches of fiberglass insulates the east and west wood-frame walls of the greenhouse.

A summer ventilation system allows hot air from the greenhouse to rise through an insulated 16-square-foot door in the ceiling of the greenhouse and be exhausted through a continuous ridge vent at the peak of the house. A 3½-foot roof overhang shades the home's southern glazing from the high summer sun.

A rock Trombe wall in the bathroom contains 41 cubic feet of cement-filled masonry block. Both sides of the wall are faced with dark native stone. Openings in the top of the wall allow warm air to rise into the bathroom or to exit through a vent into the attic and ceiling duct system. Immediately adjacent to the Trombe wall are three 18-by-60-inch Kalwall tubes filled with water. These water-storage vessels collect heat through 105 square feet of Kalwall and Thermopane® glazing.

Additional heat is stored in ten 18-by-60-inch water-filled Kalwall tubes incorporated in the south wall of the garage. These tubes are heated through 86 square feet of double-layered Kalwall glazing. Vents cut into the top and bottom of a dark plywood wall that separates the tubes from the rest of the garage permit a convective flow of air between the water tubes and the main section of the garage. A 4-foot crawlspace under the house is open to the garage for air exchange and circulation. The crawlspace is filled with 1,500 1-gallon jugs of water that store heat. This heat is radiated up through the uninsulated floor of the house. The garage doors are insulated with 1 inch of Thermax® to reduce heat loss and to help create a temperature buffer between the garage entryway and the living space.

Window Quilt® thermal curtains have been installed on 75 percent of the windows in the house. The Kosteczkos plan to hang thermal curtains in the greenhouse and on the rest of the southern glazing to further reduce evening heat loss.



## MAINTENANCE AND LIVABILITY

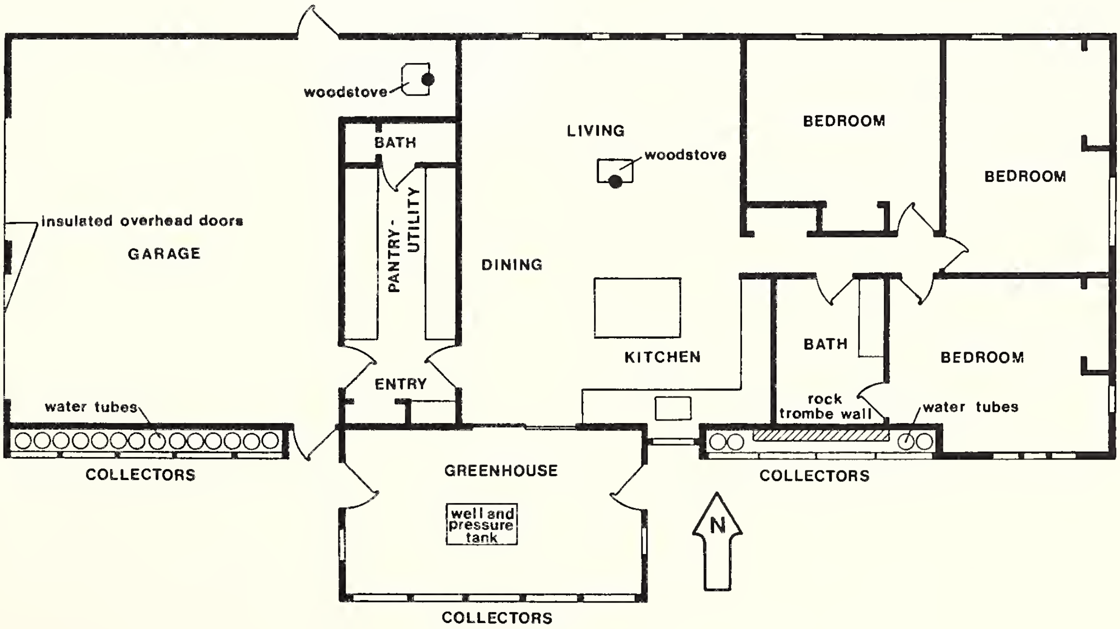
The Kosteczkos are pleased with their hybrid passive system. During the past winter, the house has been evenly heated and the Enan woodstove was needed only on extremely cold evenings. Nevertheless, they believe that heating efficiency could be improved by installing thermal curtains and building a rock mass storage wall in the greenhouse. They also suggest that the amount of heat supplied by the greenhouse could be increased by widening the opening to the living space. Additionally, heat losses due to infiltration of cold air could be reduced between the garage and utility room by installing a steel thermal door and more weatherstripping.

The summer cooling and ventilation system seems to operate effectively. During an on-site interview on a sunny day in March, 95 °F air was convected out of the greenhouse and into the attic. Temperatures in the house remained comfortable.

This hybrid passive home was built by the owners' son, a carpenter with limited construction experience, which emphasizes that building most passively heated homes is seldom more complicated than building a conventional home.

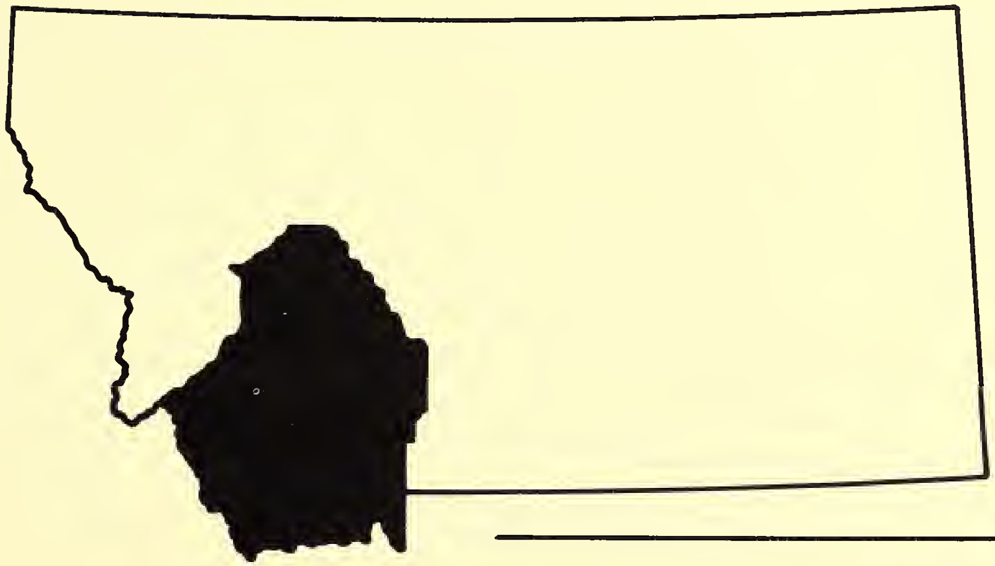
### BUILDING DETAILS

**Design type:** indirect/isolated gain
**Total floorspace:** 2,382 sq. ft.
**Heated floorspace:** 1,620 sq. ft.
**Window area** —
South: 305 sq. ft. East: 8 sq. ft.
North: 37 sq. ft. West: 4 sq. ft.
**Glazing:** two layers of glass and fiberglass
**Glazing orientation:** south
**Glazing angle:** vertical; 60 degrees (greenhouse)
**Thermal storage:** rock, water, masonry
**Auxiliary heating:** wood
**Insulation** —
Ceiling: cellulose and fiberglass to R-38
Walls: fiberglass to R-19
Floor: none
Foundation: rigid foam to R-11
Windows: thermal curtains
**Cost of materials and labor:** $65,000
**Cost per square foot:** $27
**Financing:** conventional loan
**Microclimate** —
Degree-days: 7,361
Average summer temperature: 58° F
Average winter temperature: 37° F



# ZONE II

## Southwestern Montana



# The Land and Its Climate

The Big Belts and the Crazy Mountains to the north, the Absarokees to the south, and the numerous north-south ranges in between shield this region of Montana from the climatic extremes that dominate the rolling plains to the east. Traveling east from the western edge of this zone, one encounters mountain range after mountain range—eight in all—each separated from the next by a broad river valley. Two great rivers—the Missouri and the Yellowstone—emerge from these mountains and flow eastward onto the plains. These mountains and river valleys, which have an overwhelming influence on the climate of southwestern Montana, form a "modified continental" climatic regime. This climate is characterized by abundant sunshine, light-to-moderate rainfall, summer and winter temperature extremes, and large daily temperature fluctuations.

Southwestern Montana is termed "semiarid" by climatologists, although the amount of precipitation varies considerably from the valley bottoms to the mountainsides. For example, the northern and eastern portions of the Helena valley receive less than 10 inches of precipitation in an average year, while the area along the Continental Divide, 15 miles west of Helena, could be classified as subhumid because it receives an average of almost 50 inches of precipitation each year. The greatest share of this precipitation occurs during early spring and late fall; summers and winters are relatively dry and clear.

During the October-to-May heating season, this area receives 50 to 55 percent of the sunshine possible. Average winter temperatures are generally lower in this zone than in northwestern Montana; the average temperature in Butte during the heating season is 29.3° F, as compared to 36.5° F in Libby. However, the colder temperatures in this zone are usually accompanied by clear skies.

Winters tend to be relatively cold in this area, due in part to the phenomenon of thermal stratification, a process in which the colder air prevalent at higher elevations sinks and collects in the valley bottoms. Although periods of frigid temperatures are usually short-lived, warmer air sometimes traps colder air in the valleys for extended periods.

Summer daytime temperatures in this zone are moderate and the evenings are normally cool. Temperatures of 100° F are rare, and thunderstorms occur frequently from May through August.

Due to the sheltering influence of the zone's many mountain ranges, chinook winds here generally do not have the dramatic influence on the weather that they do farther north. Although, a chinook carrying warm, dry air occasionally will affect winter weather patterns, wind is generally not a dominant climatic factor in southwestern Montana. The winds that do blow across this area are influenced predominantly by terrain—they tend to blow up and down the valleys, from the southwest during the warmer months and from the north-northwest during the winter.

**CLIMATE SUMMARY**

A) 50-55% possible sunshine* during heating season; low to moderate cloud cover

B) Insolation on vertical south wall during average heating season:
Helena — 861 Btu/ft$^2$/day
Dillon — 990 Btu/ft$^2$/day

C) 8,533 annual degree-days averaged over all stations in zone

D) Wind — usually light to moderate; summertime breezes may aid in ventilation

E) Temperatures:
Average January temp. (F°) for zone: 20.4
Average August temp. (F°) for zone: 63.4

* The actual hours of sunshine divided by the possible hours of sunshine, expressed as a percentage.

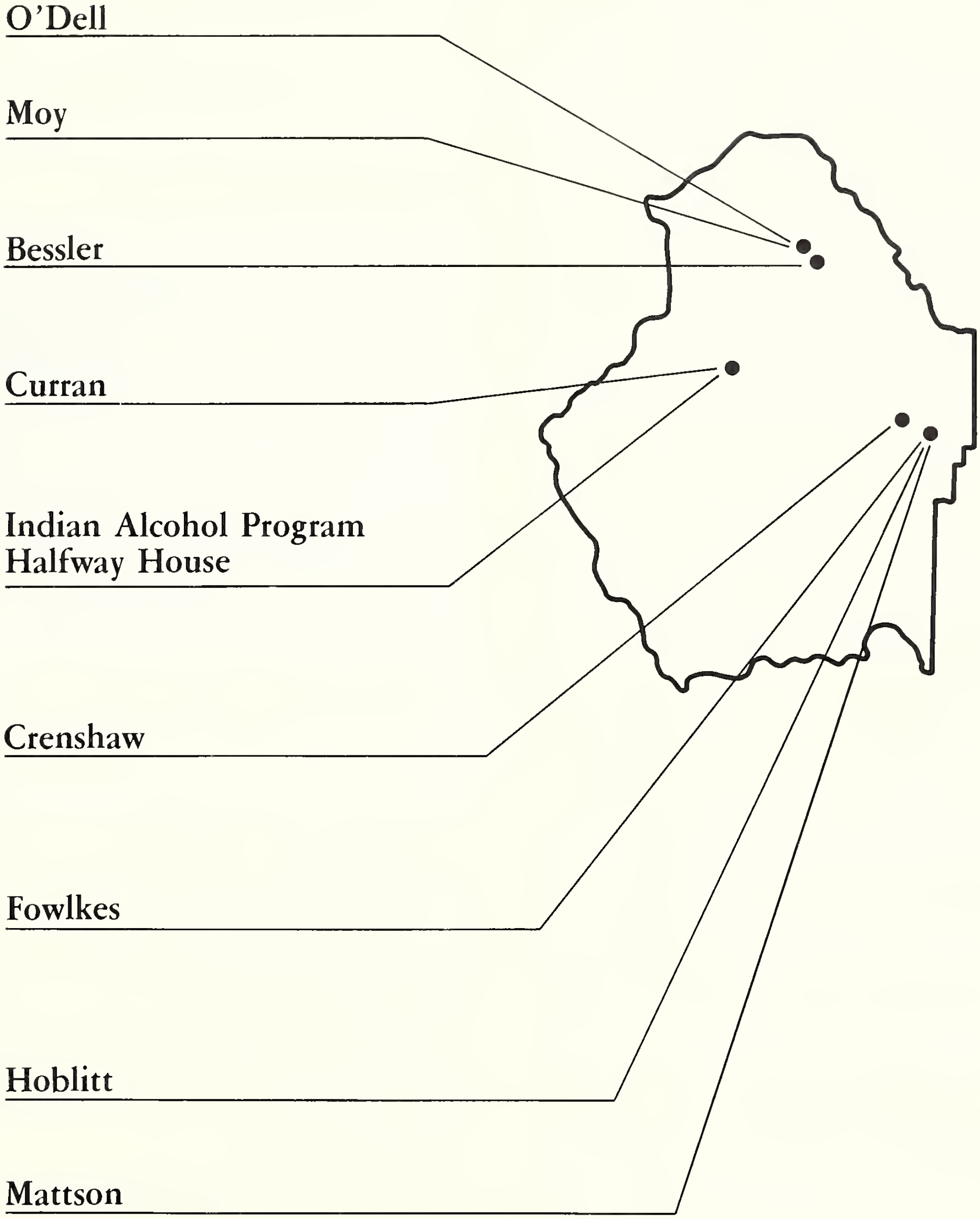
**Sources:** *WSUN #8 Montana Solar and Weather Information, Montana Solar Data Manual, Montana Renewable Energy Handbook.*

# Design Criteria For Zone II

Temperatures in this area generally are moderated by surrounding mountains. However, when low temperatures do occur, they commonly are accompanied by clear skies and a large amount of solar radiation. Overheating can be a problem on clear, sunny, winter days if heat storage and movable insulation are neglected in a building's design. The heating load in buildings throughout this zone is usually high due to the cooler temperatures common at higher elevations. Therefore, a well-insulated structure is a prerequisite to using a passive solar system here.

## GLAZING

According to Balcomb's Passive Solar Design Handbook, discussed in the design criteria section for Zone I, a south-facing window area that represents 16 to 32 percent of the total floor area in a Dillon home can be expected to reduce the home's annual heating needs by 24 to 32 percent, or by 54 to 77 percent with R-9 nighttime window insulation. The same size house in Helena can be expected to have a 21 to 25 percent lower heating load with a south-facing window area that represents 20 to 34 percent of its total floor area. This home's heating needs would be reduced by 55 to 77 percent with R-9 nighttime window insulation.


O'Dell
Moy
Bessler
Curran
Indian Alcohol Program Halfway House
Crenshaw
Fowlkes
Hoblitt
Mattson

# Ernest O'Dell

## BUILDING DESCRIPTION

The O'Dell house, located north of Helena on a grassy, open site, employs an envelope system to distribute passively heated air throughout its two-story, three-bedroom layout. A two-story solarium on the south is separated from the living space by sliding glass doors that allow natural light and solar-heated air to enter the house. An attached garage on the northwest and a vestibule entry to the kitchen contribute to the effectiveness of the O'Dell's envelope design.

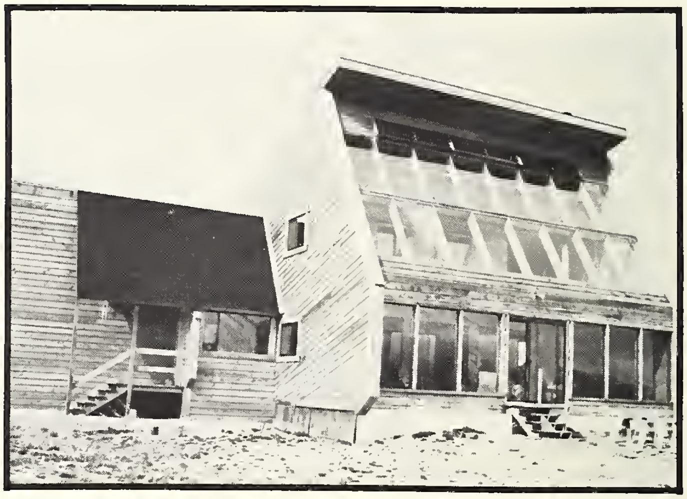
As in all envelope homes, insulation is crucial to the performance of this system. The home's full concrete basement, used to store heat, is insulated on the exterior with 2 inches of rigid foam. All exterior walls are insulated with 6 inches of fiberglass and are lined with a 4-mil polyethylene vapor barrier on the interior surface. The inner solarium wall, the upstairs ceiling, and the inner north wall are framed with 2-by-4-inch studs and insulated with 3 ½ inches of fiberglass. The solarium roof and main shed roof are both framed with T.J.I.® structural wood joists and insulated with 9 inches of fiberglass.

## SOLAR SYSTEM

The envelope of the house consists of the south solarium space, which is glazed with 592 square feet of Thermopane® glass, an insulated attic, and a 12-inch-wide plenum between the double north walls. The airspace provided by the solarium, attic, and plenum creates a tempered environment around the living space that effectively buffers outdoor temperature extremes and reduces heat loss.

Collected heat moves from the solarium into the living space through doors and windows in a common wall between the two areas. The designer states that the airspace surrounding the "inner house" serves as a path for convective air movement and as a mechanism for bringing warmed air into the basement for thermal storage.

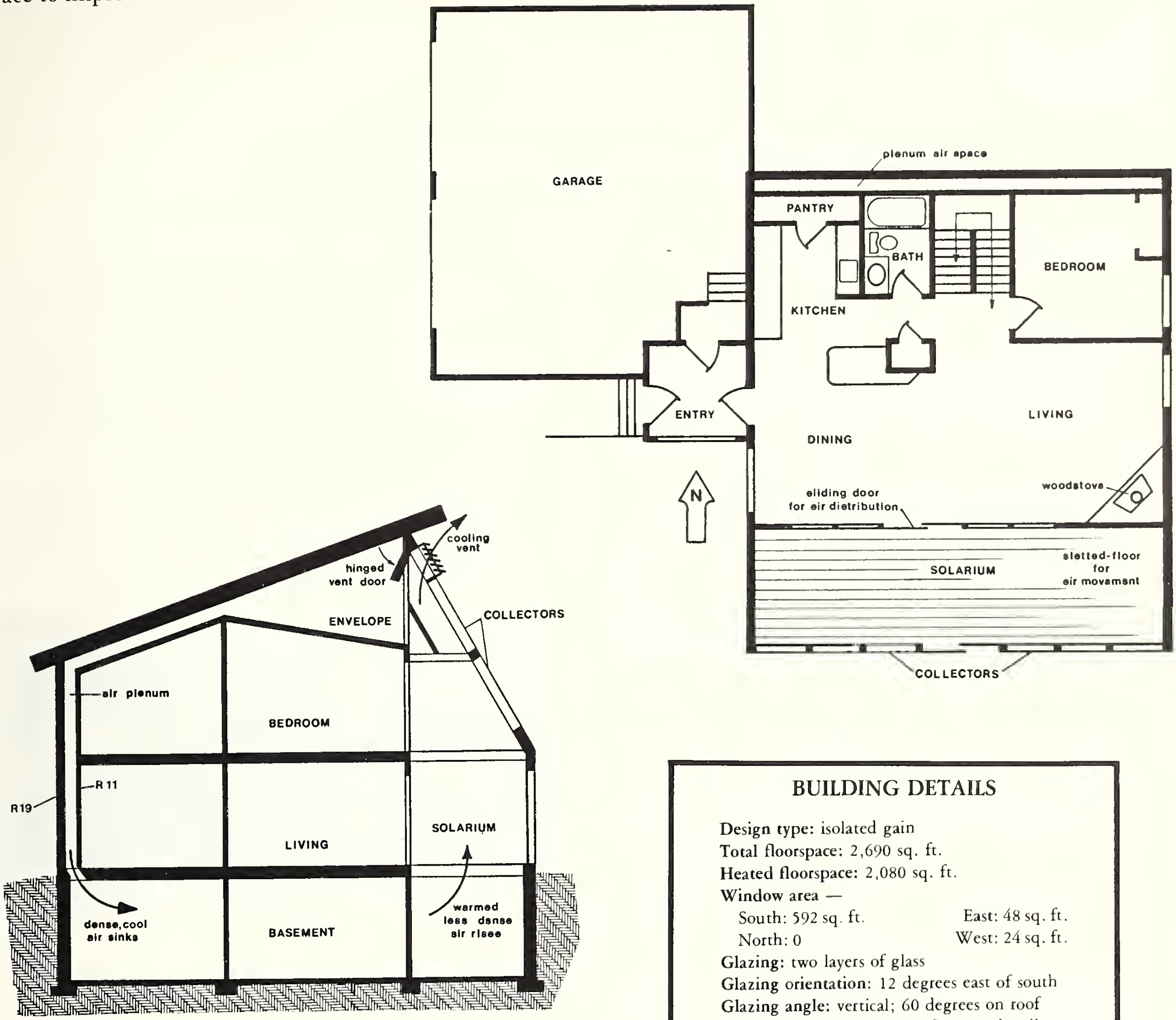
Summer cooling is promoted by opening basement windows. When they are open, cool air rises into the solarium through the slatted wood floor, displacing warmer air that leaves through a vent in the solarium roof.



## MAINTENANCE AND LIVABILITY

The insulative qualities of the double wall and plenum airspace combine to reduce heat loss and to increase the thermal efficiency of the house. O'Dell estimates that 75 percent of his heating needs are met by the sun. Less than one cord of wood was burned in the home's fireplace for auxiliary heat during the winter of 1980-81, although some electric baseboard heat was used to supplement fireplace heat. Indoor temperatures fluctuated from a low of 58°F to a high of 72°F during the heating season.

Although O'Dell is satisfied with the performance of his home, he recommends that anyone building this type of structure: use less glazing in order to reduce evening heat loss and summer overheating; install thermal curtains on the solarium to reduce heat loss; plan for more east-west windows to aid summer cooling; and add more windows between the solarium and the living space to improve distribution of heated air.



## BUILDING DETAILS

**Design type:** isolated gain
**Total floorspace:** 2,690 sq. ft.
**Heated floorspace:** 2,080 sq. ft.
**Window area** —
  South: 592 sq. ft.    East: 48 sq. ft.
  North: 0    West: 24 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** 12 degrees east of south
**Glazing angle:** vertical; 60 degrees on roof
**Thermal storage:** basement floors and walls
**Auxiliary heating:** fireplace, electric baseboard
**Insulation** —
  Ceiling: fiberglass to R-38
  Walls: fiberglass to R-19;
    interior wall: fiberglass to R-11
  Floor: none
  Foundation: rigid foam to R-11
  Windows: none
**Cost of materials and labor:** $62,000
**Cost per square foot:** $23
**Financing:** conventional loan
**Microclimate** —
  Degree-days: 8,190
  Average summer temperature: 63°F
  Average winter temperature: 31°F

Helena

# Richard and Margaret Moy

## BUILDING DESCRIPTION

This conventional looking, two-story, four-bedroom house incorporates extensive south glazing and a large stone fireplace into a simple and effective passive design. The Moy house, located on a gently sloping, open site north of Helena, is sheltered on the northwest corner by an attached garage and by several large hills.

A vestibule entry on the south opens to a living room, a study, and bedrooms. The kitchen, dining area, bathroom, and storage-utility area along the north wall are separated from the rest of the living space by a large stone fireplace extending the full two-story height of the building. Outside access to the north is through a utility room off the attached garage.

Although the foundation of this 2,400-square-foot house is not insulated, the rim joist is insulated with 6 inches of fiberglass. The 2-by-6-inch studwalls also contain 6 inches of fiberglass. The home's simple gable roof, insulated with 12 inches of fiberglass, has a 28-inch overhang to shade the home in the summer. A balcony overhang on the second floor shades the south-facing windows on the lower level during the summer. Other energy conserving features include a 4-mil polyethylene vapor barrier between the insulation and the living space, steel thermal doors with magnetic weatherstripping, and triple-glazed, wood-frame windows.

## SOLAR SYSTEM

A 1,248-cubic-foot, cement-filled, cinder block fireplace in the Moy house stores heat collected through 297 square feet of south glazing. Dark stone covering the fireplace and chimney and dark red sidewalk bricks placed on the floor just inside the south windows on the first floor increase the amount of heat that can be stored in the home.

A complex system of heat exchange flue pipes buried in the hearth mass allows outside combustion air to be preheated before it enters the house; this air enters through a register below a Vigilant® woodstove. Two fans in the hearth blow warmer, stratified air through ducts from the second floor down to the main floor and basement to supplement the natural radiation and convection of heat from the fireplace.

Summer cooling features include a roof overhang on the south, good insulation, and casement windows that can be opened to increase cross-ventilation.

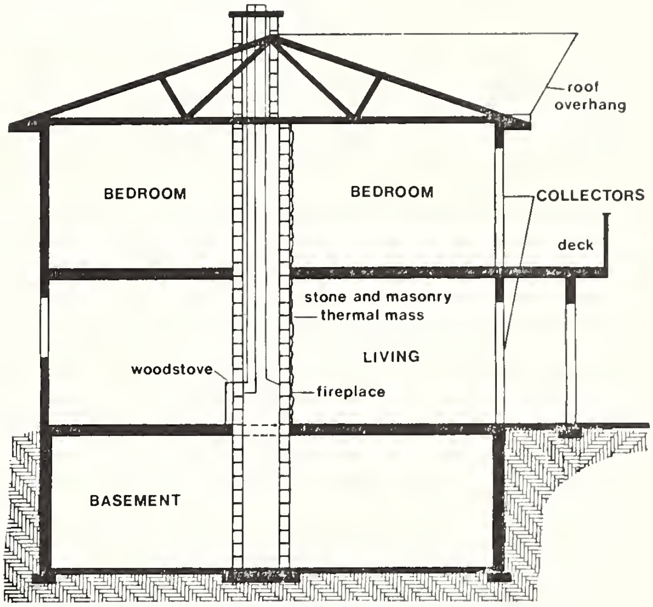
## MAINTENANCE AND LIVABILITY

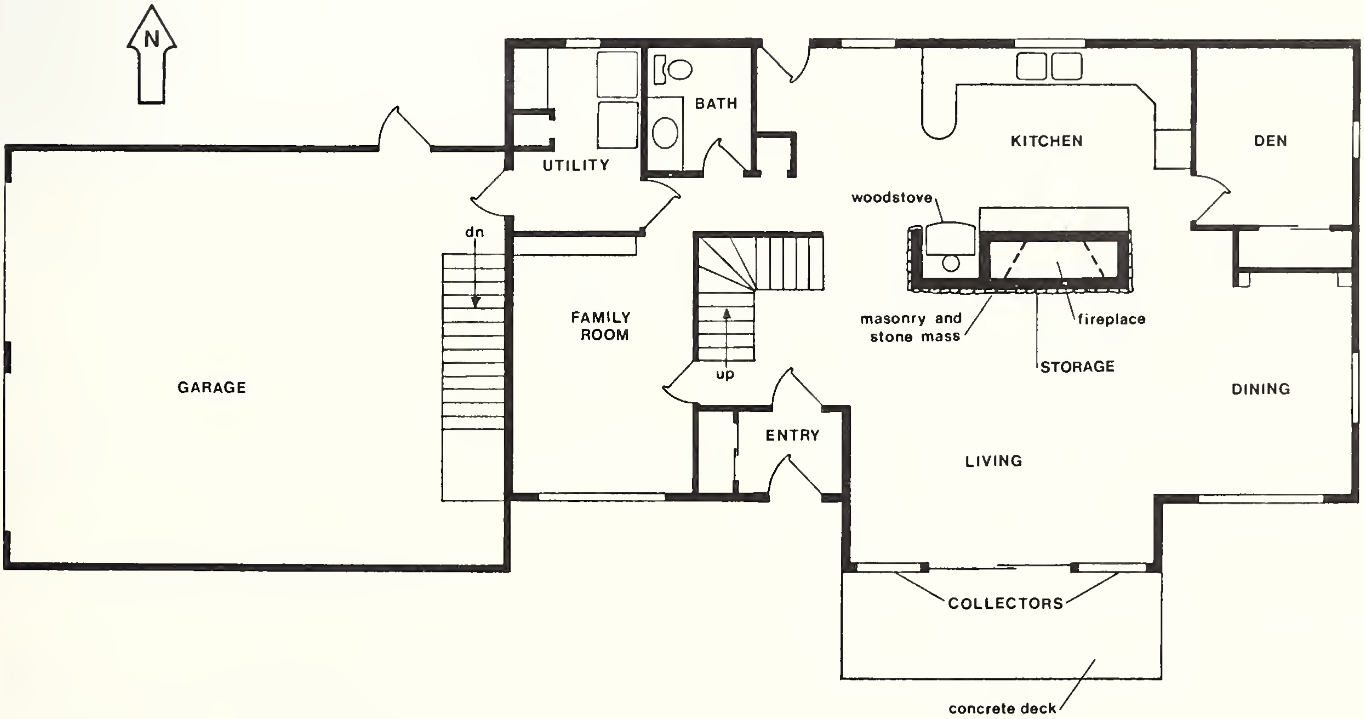
The large amount of thermal storage helps to prevent drastic temperature fluctuations. Indoor winter temperatures range from 72°F during the day to 58°F in the evening. Two cords of wood were burned for auxiliary heat during the past winter. Electric baseboard heaters were not used.

Owner recommendations for changes in design include insulating the foundation's exterior and adding a greenhouse. Installing movable window insulation would further reduce heat loss. The Moys say they would probably consider an earth-sheltered design if they were to build again.

## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 3,600 sq. ft.
**Heated floorspace:** 2,400 sq. ft.
**Window area** —
South: 297 sq. ft. East: 34 sq. ft.
North: 37 sq. ft. West: 5 sq. ft.
**Glazing:** three layers of glass
**Glazing orientation:** 13 degrees east of south
**Glazing angle:** vertical
**Thermal storage:** masonry, stone, and concrete
**Auxiliary heating:** wood, electric baseboard
**Insulation** —
Ceiling: fiberglass to R-38
Walls: fiberglass to R-19
Floor: none
Foundation: none
Windows: none
**Cost of materials and labor:** $57,600
**Cost per square foot:** $16
**Financing:** conventional loan
**Microclimate** —
Degree-days: 8,190
Average summer temperature: 63°F
Average winter temperature: 31°F





Montana City

# Paul and Barbara Bessler

## BUILDING DESCRIPTION

The Besslers' earth-sheltered, passive home is built into a grassy hillside southeast of Helena near Montana City. The site's good southern exposure is enhanced by a man-made pond directly south of the house that reflects winter sunlight into the home.

The floorplan of this single-level, three-bedroom house is open—except for partitions in the bedrooms and bath, no walls were constructed that could impede a flow of air throughout the house. Clerestory windows running the length of the house increase natural lighting and ventilation.

Oversized concrete footings support 8-inch reinforced concrete walls on the north, east, and west. All these walls were waterproofed with asphalt emulsion, covered with 6-mil polyethylene, and insulated on the exterior with 2 inches of Styrofoam Blueboard®. Poured-concrete buttresses along the inside of the north wall counter the inward pressure exerted by the hillside while forming partition walls between the bedrooms.

Conductive heat loss was reduced by installing a staggered 2-by-4-inch stud wall on a 2-by-6-inch top and bottom plate for the south wall. This design prevents any single stud from being in direct contact with both the interior and exterior walls. The exterior wall was sheathed with 2-inch Styrofoam Blueboard® and plywood. The inner studwall was filled with 3½ inches of ThermoCon®, a wet-spray cellulose. Sheetrock was hung and the wall was sealed with a vapor barrier paint.

The home's opposing-shed roof and clerestory window wall are supported by T.J.I.® truss joists that sit on a steel I-beam in the middle of the house. The roof is insulated with 9 inches of fiberglass between the joists. A 6-mil polyethylene vapor barrier separates the fiberglass from the living space. The top of the roof is sheathed with ¾-inch plywood and coated with asphalt emulsion. Three layers of 6-mil polyethylene cover the asphalt, which, in turn, is covered with 8 inches of native soil. A fascia board on the east and west edges of the roof holds the soil in place. A mansard roof overhang on the south performs a similar function, and shades the south wall windows in the summer.

## SOLAR SYSTEM

Solar heat is collected directly through 218 square feet of south-facing, double-glazed windows. Heat is stored in the concrete floor, which is covered with dark native stone. Supplemental heat radiates from 100 feet of 1-inch copper pipe buried in the concrete floor beneath the living room and bedroom. This pipe is connected to a heating coil in the home's woodstove. When the water temperature in the stove reaches 120°F, a small Grundfos pump moves water through the heating coil and into the buried copper pipe.

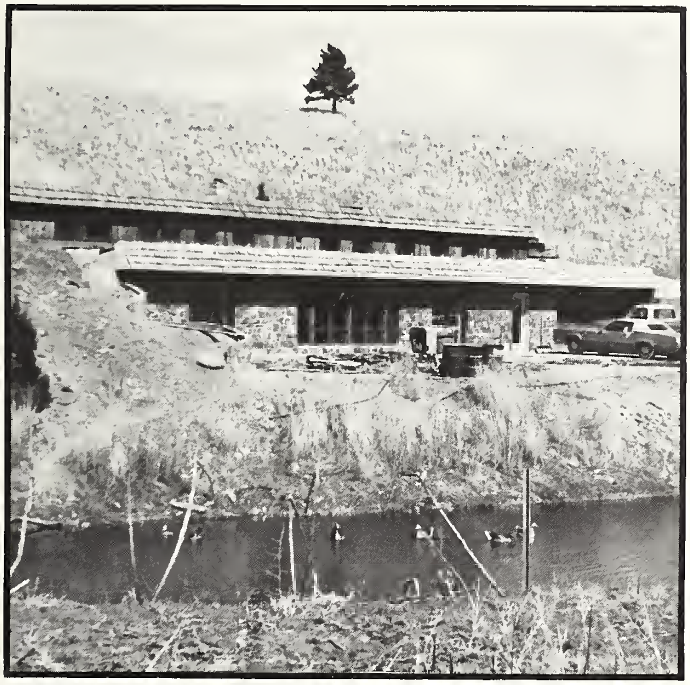
Like the home's concrete floor and walls, a 12-foot-high masonry hearth stores collected solar heat. The hearth also stores heat produced by the woodstove. Cooler, denser air falls to a sunken floorspace around the hearth, where it is heated, drawn upward by convection, and circulated throughout the house. Nighttime heat loss through the south glazing is reduced by pulling thick polyester blankets across the windows.

A 3-foot roof overhang on the south shades the windows from the high summer sun. Ventilation is increased by opening doors and casement windows on the main floor and awning windows in the clerestory beneath the peak of the north-sloping roof.

## MAINTENANCE AND LIVABILITY

This well-insulated, earth-sheltered house maintains a relatively constant temperature throughout the heating season at a humidity of about 35 percent. During the winter, daytime temperatures average 64°F; the minimum evening temperature has been 60°F. Two cords of wood were burned in the woodstove for auxiliary heat during the winter of 1981. The efficiency of the homemade stove was increased by installing a 4-inch combustion air intake duct to the outside.

The Besslers recommend that prospective builders consider ventilation, natural lighting, and wall construction carefully before building an earth-sheltered home. One design change they would consider is constructing a movable soffit to control incoming sunlight during the spring and fall. This overhang would be hinged at the top, and raised and lowered by a worm gear.



### BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 2,880 sq. ft.
**Heated floorspace:** 2,160 sq. ft.
**Window area** —
  South: 218 sq. ft.  East: 0
  North: 0  West: 0
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** masonry, rock
**Auxiliary heating:** wood
**Insulation** —
  Ceiling: cellulose to R-30
  Walls: cellulose and Blueboard® to R-28
  Floor: rigid foam to R-11
  Foundation: rigid foam to R-11
  Windows: polyester blankets
**Cost of materials and labor:** $78,000
**Cost per square foot:** $27
**Financing:** owner
**Microclimate** —
  Degree-days: 8,129
  Average summer temperature: 63°F
  Average winter temperature: 31°F

## Butte

# Brian Curran

## BUILDING DESCRIPTION

This conventional-looking, three-bedroom home in a subdivision on the south side of Butte features an innovative use of superinsulation and passive design known as ''micro-load'' solar. In constructing his home, Curran substituted the extensive south glazing inherent in a standard passive design for the benefits provided by a roof superinsulated to R-60 and walls superinsulated to R-40. Although some direct solar gain does provide supplemental heat to the house, the keys to the success of this design are its airtight construction, internal sources of heat gain, and insulation levels.

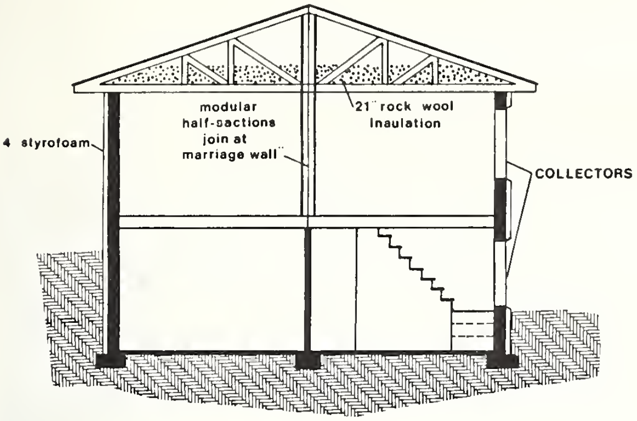
A modular building that was built in two halves and joined on the site, the Curran home was set on a previously poured concrete foundation and a 4-inch-thick, insulated concrete slab. The exterior 2-by-6-inch studwalls were filled with 6 inches of fiberglass. The outside of these walls was finished with 4 inches of specially cured polystyrene. Metal corner bracing was used to give diagonal strength to the walls. The entire exterior surface of the walls was sheetrocked with ½-inch, water repellent wallboard. The polystyrene panels were glued to the sheetrock with a waterproof mastic adhesive, covered with a nylon mesh, and textured with an acrylic-based stucco. These polystyrene panels extend below grade to the foundation footing to form an unbroken insulative envelope around the entire house. The polystyrene insulation is protected from soil moisture by its stucco finish. Another layer of insulation protects the inside of the 2-by-4-inch foundation wall, which was filled with 3½ inches of fiberglass insulation.

The truss, gable roof was filled with 21 inches of rockwool. During the process, an airspace was left for attic ventilation. A polyethylene vapor barrier lines the inside surface of the foundation wall, the interior side of the perimeter walls, and the ceiling. The builders were careful not to puncture this vapor barrier during construction. Also, track lighting was installed to lessen the number of holes needed to install electric fixtures in the ceiling. To complete the home's airtight construction, the builders installed foam-core steel doors with magnetic weatherstripping and triple-glazed wood-frame windows.

Two air-to-air heat exchangers periodically exhaust warm, stagnant air and draw fresh air into the home. As the stagnant air is exhausted and fresh air is drawn in, heat from the warmer, outgoing air is transferred to the cooler incoming air across a series of thin baffles. Such an air preheating scheme effectively reduces heat loss from the home. The heat exchangers also act as an effective ventilation system to reduce moisture buildup inside the house and to exhaust indoor pollutants such as cooking odors, aerosol spray particles, and carbon monoxide.

## SOLAR SYSTEM

The amount of solar collection surface needed for this micro-load passive home was greatly reduced because of its airtight construction and the large amount of insulation used. This passive house incorporates only 78 square feet of south glazing for collecting solar heat and requires no storage system. When the sun shines during the winter, the house warms rapidly without auxiliary heat. The heating needs of this structure are so low, in fact, that the small amount of passive solar gain, along with waste heat from people and appliances, is usually enough to heat the house.



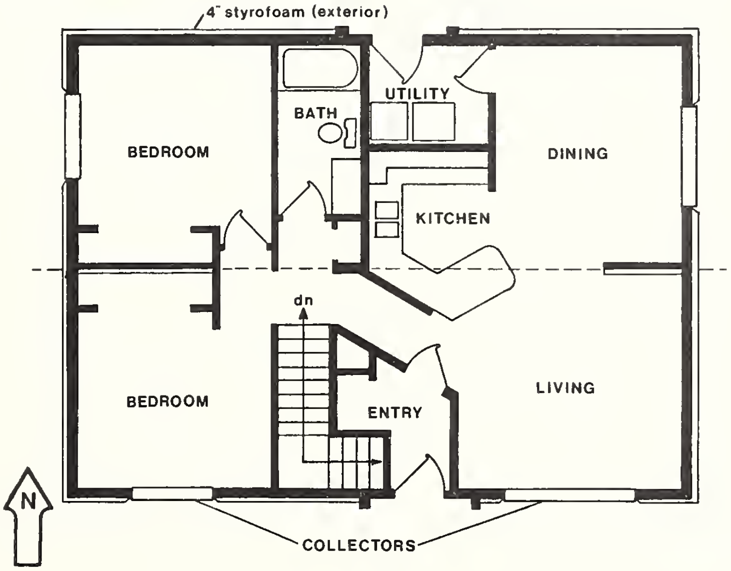
**BUILDING DETAILS**

**Design type:** superinsulated, direct gain
**Total floorspace:** 2,100 sq. ft.
**Heated floorspace:** 2,100 sq. ft.
**Window area** —
South: 78 sq. ft.
East: 38 sq. ft.
North: 0
West: 16 sq. ft.
**Glazing:** three layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** none
**Auxiliary heating:** electric baseboards and appliances
**Insulation** —
Ceiling: rockwool to R-60
Walls: fiberglass and polystyrene to R-40
Floor: none
Foundation: fiberglass and polystyrene to R-25
Windows: none
**Cost of materials and labor:** $55,000
**Cost per square foot:** $26
**Financing:** conventional loan
**Microclimate** —
Degree-days: 9,719
Average summer temperature: 57°F
Average winter temperature: 29°F

## MAINTENANCE AND LIVABILITY

Electric baseboard heaters, totaling 17 feet in length, provide backup heating for this 2,100-square-foot home. During February 1981, when temperatures in Butte were 11 percent above normal, the amount of electricity needed to heat the Curran home was 80 kWh, for a total cost of $2.40. The house maintains a winter temperature between 68° and 72°F. Humidity in the home ranges between 50 and 60 percent.

The builder maintains that this micro-load, superinsulated, passive home costs only about $1 more per square foot to construct than a conventionally insulated house with R-19 walls and R-38 ceiling.



**Butte**

# Indian Alcohol Halfway House

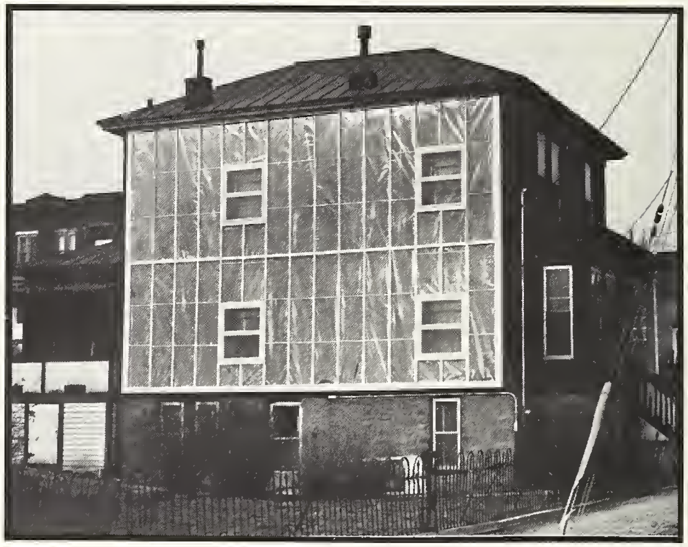
## BUILDING DESCRIPTION

The Indian Alcohol Program halfway house in Butte is a three-story brick building built before 1900. The basement contains kitchen facilities; the main floor and top level house seven bedrooms. Located on a hill overlooking the city, the building offers a good southern exposure for collecting solar heat. Program directors took advantage of this exposure by retrofitting the building's entire south wall with a triple-glazed surface to collect heat. This design allows the existing brick wall just inside the glazing to be used as a massive thermal storage wall. The wall was painted with two coats of Columbia Ebony®, a latex-based, heavy-bodied stain, to increase its ability to absorb heat.

The collector frame, constructed from 2-by-4-inch studs, was assembled on the ground in 6-by-10-foot sections and attached to the brick wall with lag bolts and lead shields. The frame's perimeter was boxed and filled with fiberglass insulation. The joints between the frame and the wall were sealed with silicone caulk.

The collector is triple-glazed with three layers of 3M Flexgard®. The first layer was attached to the frame with a double-adhesive vinyl foam tape. The middle and outer layers were attached to precut 2-by-10-foot aluminum storm window frames with a 3M transfer adhesive. Before mounting, 1-by-2-inch wooden spacers were attached to the inner layer of glazing. The preassembled panels then were attached to the wooden spacers. All horizontal frame surfaces were caulked to prevent water from entering the collector. Four Anderson awning windows, which can be opened from inside, were installed in the collector and the wall so that the building could be vented during the summer.

The roof was insulated with 8 inches of dry-blown cellulose. The walls were retrofitted with 2 ½ inches of Insulwal®, a polyurethane foam board faced with sheetrock. This saved several steps in insulating and remodeling the inside of the perimeter walls.



## SOLAR SYSTEM

The existing south wall provides 672 cubic feet of thermal mass, while the preassembled glazing panels create a 580-square-foot collection surface. The inner glazing is 4 inches from the brick wall. Heat flow between this airspace and the living area is regulated through the building's existing windows. Heat collected by the wall during the day radiates into the living area in the evening. Insulation added to the north, east, and west walls helps to retain the stored heat.

The building is cooled by venting excess heat through the awning windows in the wall, and by opening windows on the other walls.

## MAINTENANCE AND LIVABILITY

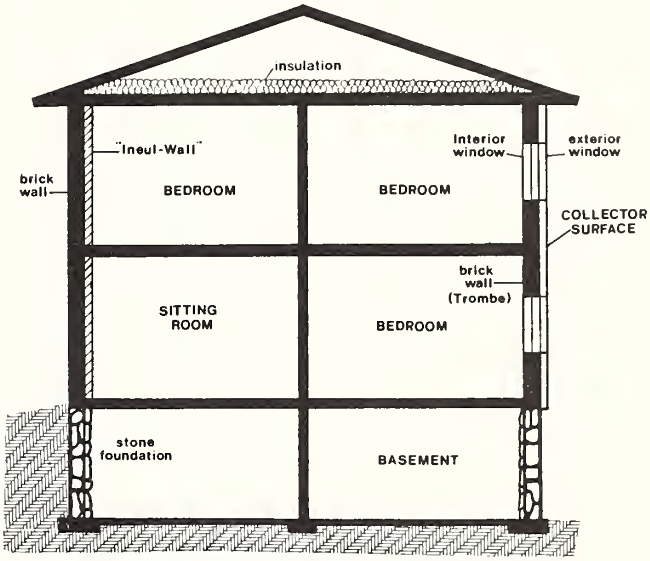
Although extensive monitoring information is not yet available, the National Center for Appropriate Technology in Butte has begun gathering data on the effectivenss of the retrofitted south wall. Some observations were made with a digital, heat-probing thermometer during a sunny day in October. Although the high temperature on that day was 70°F, shortly after noon the surface temperature of the exterior surface of the wall was 135°F. At the same time, air flowing into the house reached 115°F. Air flowing into the unglazed first floor wall was 80°F. That evening the temperature in Butte dropped to 26°F, and by the following morning the temperature of the exterior surface of the wall had dropped to 78°F. Despite these external temperature changes, the temperature of the interior wall surface remained 80°F.

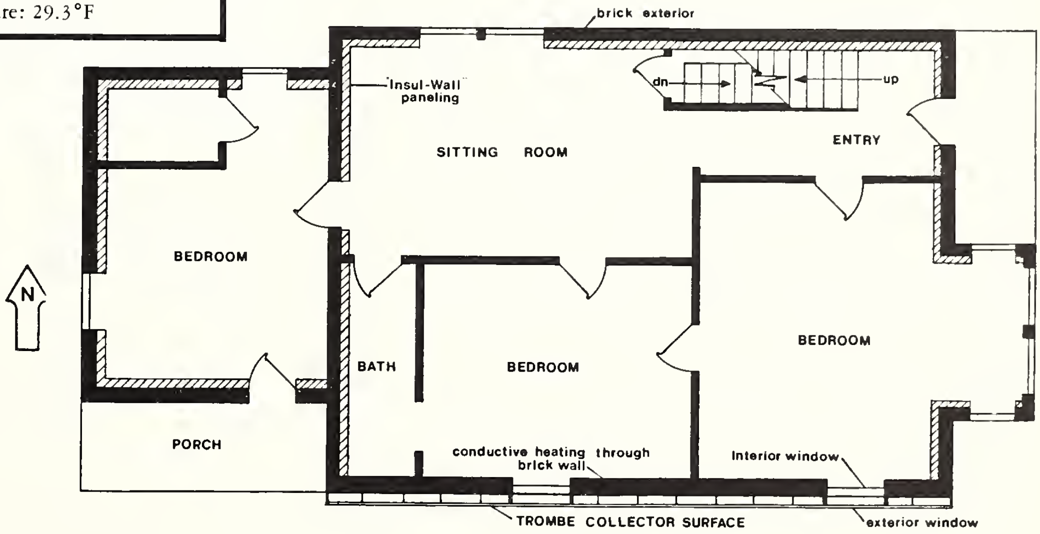
Using fuel consumption data and U.S. Weather Service degree-day data for 1978 through 1980, a 38 percent savings in fuel was calculated as a result of the solar retrofit and building weatherization. This 2,500-square-foot building is supplementally heated by gas space heaters. Unfortunately, they don't have thermostatic controls and sometimes continue to operate when not needed. Fuel savings could be increased by more carefully scheduling the opening and closing of windows in the south wall and more efficient use of the space heaters. Overheating in the summer has not been a problem, due in part to normally cool summer nights at Butte's altitude.

The project's designer has calculated that the project's estimated payback period could have been cut from 25 to 12 years by spending the money invested in the south wall retrofit to increase insulation throughout the building. Nevertheless, the halfway house retrofit demonstrates that elements of passive solar design and improved insulation can be used to increase the heating efficiency of older buildings.

## BUILDING DETAILS

**Design type:** indirect gain retrofit
**Total floorspace:** 2,500 sq. ft.
**Heated floorspace:** 2,500 sq. ft.
**Window area** —
  South: 580 sq. ft. East: 113 sq. ft.
  North: 105 sq. ft. West: 43 sq. ft.
**Glazing:** three layers 3M Flexgard®
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** brick
**Auxiliary heating:** gas spaceheaters
**Insulation** —
  Ceiling: cellulose to R-30
  Walls: Insulwal® to R-20
  Floor: none
  Foundation: Insulwal® to R-20
  Windows: none
**Approximate total cost:** $10,000
**Cost per square foot:** not applicable
**Financing:** Department of Energy grant
**Microclimate** —
  Degree-days: 9,719
  Average summer temperature: 56.7°F
  Average winter temperature: 29.3°F





Churchill

# David and Shirley Crenshaw

## BUILDING DESCRIPTION

An open, south-facing hillside outside Churchill shelters the Crenshaws' underground concrete home. The home's living room, dining room, and two bedrooms are heated directly through south-facing windows. Even the kitchen, located on the home's north side, receives light and heat from the low-angled winter sun. An underground, two-car garage provides access to the house from the north while sheltering the living space from severe winds and cold temperatures.

The house walls are 8 inches of reinforced concrete with a textured brick finish, cast by the shape of the form. The foundation wall is waterproofed with asphalt emulsion and insulated with 2 inches of rigid foam. The perimeter of the wall is lined with perforated plastic pipe to ensure proper drainage.

A unique feature of the Crenshaw house is its post-tensioned concrete roof, formed and poured in place. Prior to pouring the 8-inch-thick concrete roof, a network of 3/8-inch cables was laid across the roof above the forms. The cables were positioned 10 inches apart and perpendicular to the cast-in-place concrete main beam that runs the length of the living room. Five to seven days after the cement was poured, the free ends of the cables were tied off under tension. The cables provide the structural strength necessary for an underground house at a lower cost than structural concrete. The concrete roof was finished with ½ inch of bentonite, insulated with 5 inches of rigid foam, and backfilled with 18 inches of soil.

## SOLAR SYSTEM

Heat collected through 170 square feet of double-glazed windows is stored in the concrete floor, walls, and ceiling. The dark, brushed-aggregate concrete floor, 5 inches thick, provides thermal storage. Storage efficiency was increased by insulating the outside of the south frost wall with 2 inches of rigid foam, by filling the 2-by-10-inch studwall on the south with 9 inches of fiberglass, and by installing a vapor barrier on the interior surface.

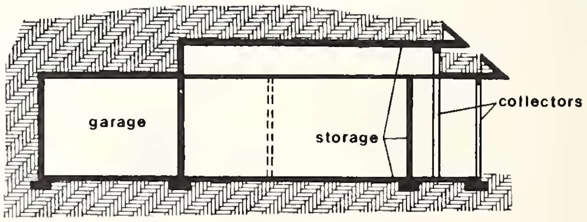
A 30-inch overhang shades the south windows to prevent overheating during the summer. Ventilation is increased by opening south windows.

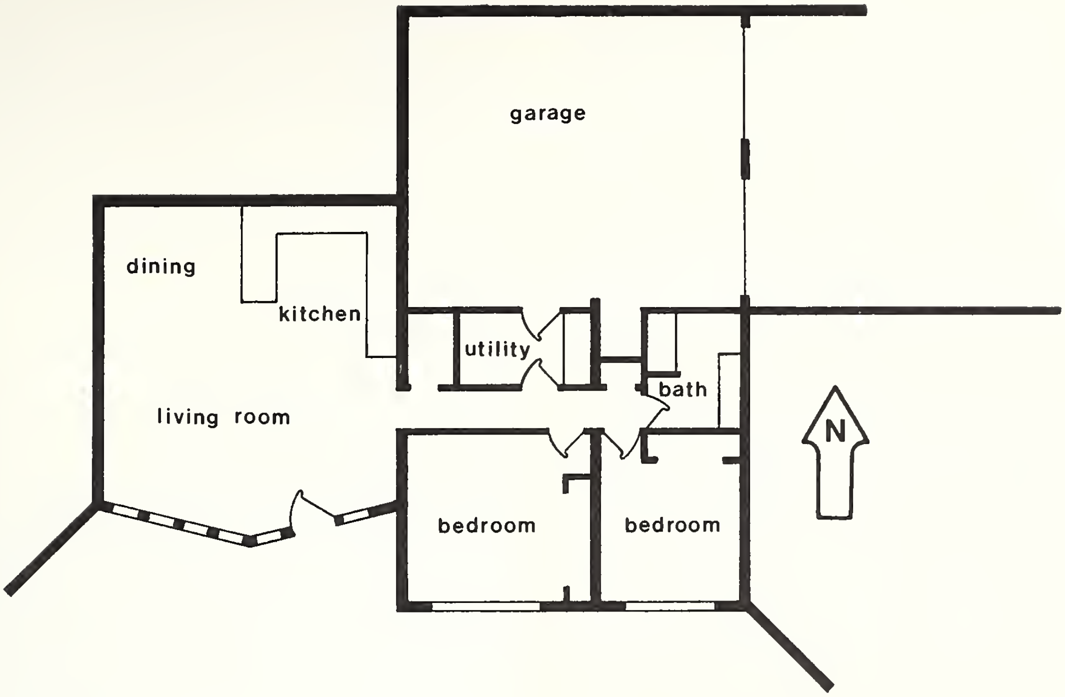
## MAINTENANCE AND LIVABILITY

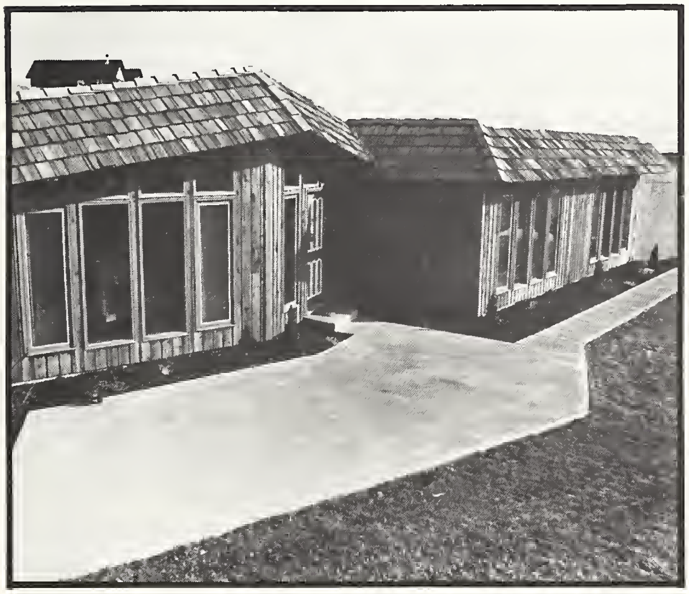
Winter temperatures in the Crenshaw house range from a low of 65°F, without auxiliary heat, to a high of 72°F. The backup heating source, an electric forced-air furnace, consumed an average of 553 kWh of electricity per month through the heating season. The furnace duct system, buried in the concrete floor, includes a fan to circulate heated air throughout the house.

The light-colored masonry walls inside the house help reflect natural light, while the large concrete mass and the open floorplan help to store and distribute heat more evenly.

The Crenshaws believe that the post-tensioned, concrete roof was a good choice because it could be fabricated locally and because it was less expensive than prestressed concrete panels. They suggested that adding thermal curtains or insulating shutters would help to reduce nighttime heat loss.







## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 2,330 sq. ft.
**Heated floorspace:** 1,470 sq. ft.
**Window area** —
- South: 170 sq. ft.
- East: 0
- North: 0
- West: 0

**Glazing:** three layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** concrete
**Auxiliary heating:** electric furnace
**Insulation** —
- Ceiling: rigid foam to R-28
- Walls: rigid foam and fiberglass to R-30
- Floor: rigid foam to R-5.5
- Foundation: rigid foam to R-11
- Windows: insulated curtains

**Cost of materials and labor:** $54,000
**Cost per square foot:** $23
**Financing:** FHA loan
**Microclimate** —
- Degree-days: 8,082
- Average summer temperature: 61°F
- Average winter temperature: 34°F

Bozeman

# Charless Fowlkes

In 1976, Charless Fowlkes of Bozeman was awarded a $10,000 grant from Montana's Renewable Energy Program to install a passive solar space-heating system in conjunction with a custom-designed wood furnace. To make arrangements to visit the home or to obtain more information on the project, contact Fowlkes at 31 Gardner Park Drive, Bozeman, MT 59715; telephone 587-3779.

## BUILDING DESCRIPTION

Built in a subdivision south of Bozeman, the Fowlkes residence is a two-story, two-bedroom, wood-frame building situated in a flat valley bottom. The house is shaded on the west by a grove of deciduous trees, and is sheltered from northerly winds by an attached garage and shop, a wood storage area, and neighboring buildings. An exterior stairway on the south provides access to an upstairs kitchen, dining room, and living room. A ground-level entrance on the south furnishes access to the bedrooms, bathroom, and office.

The house foundation was constructed to accommodate the 18-ton weight of water-filled tubes used to store solar heat. On the south wall, an extra-wide footing supports two 8-inch reinforced concrete foundation walls. The walls were placed 4 feet apart and capped with a 7-inch reinforced concrete slab. This concrete "box beam" evenly distributes the added weight of the water tubes. The foundation's exterior was waterproofed and insulated with 2 inches of rigid foam.

The 2-by-6-inch exterior walls are insulated with 6 inches of fiberglass; a polyethylene vapor barrier covers the insulation. The interior walls were built by the post-and-beam method. The vaulted ceiling is filled with 12 inches of fiberglass and lined with a vapor barrier.

## SOLAR SYSTEM

Fowlkes' passive solar heating system employs 482 square feet of south-facing, vertical Thermopane® windows to collect heat. Twenty water-filled fiberglass tubes, 16 inches wide by 17 feet tall, store heat and serve as a water Trombe wall. The tubes, set 12 inches from the glazing, are insulated from the concrete floor by 5/8-inch particleboard and 1 inch of rigid foam. Solar absorption was increased by painting the south side of the tubes with a flat, dark enamel. Illumination of the home's interior was enhanced by painting the north side of the tubes a reflective off-white color.

To reduce heat loss at night and during cloudy weather, Fowlkes installed a thermal curtain, which can be lowered like a large window shade to shield the water mass from the exposed glazing. The curtain consists of an outer fabric of 6-ounce white dacron sailcloth filled with 6 inches of 10-ounce Polarguard® . The interior surface of the curtain, consisting of a waterproof nylon "pack cloth," acts as a vapor barrier. Total insulation value of the curtain is estimated at R-5.

A motorized system was developed and installed for rolling and unrolling the curtain. Steel rollers, 6 inches in diameter and 15 feet long, support the curtain. The rollers are supported on stub shafts carried in roller bearings. A 3/8-inch bolt rope or welting was inserted through a guide in the edges of the curtain. The guide, made by slitting a ¾-inch plastic tube lengthwise, serves as a track to control the curtain as well as a seal to lessen heat loss around its edges. A ⅓-horsepower reversible-gear motor operates a chain drive to turn the rollers. The curtain can be fully rolled or unrolled in about one minute.

The storage tubes extend from the foundation wall, through the first floor, and up into the second floor. These tubes, which supply heat to the entire living area, can store enough heat to warm the home for three days. Although the house does not have an overhang to shade the south glazing, the thermal mass of the water tubes can moderate summer temperatures and prevent overheating. Due in part to the higher angle of the summer sun, the effective collector area is reduced by about 50 percent.

## MAINTENANCE AND LIVABILITY

Extensive monitoring of the Fowlkes home was conducted as part of a monitoring program funded with another Renewable Energy Program grant. The results of the monitoring, which are available to the public, indicate the home's annual solar fraction to be 82 percent. A wood stove provides backup heating during extremely cold periods.

Monitoring results suggest that the solar heating contribution could not be increased by economically feasible means. If a window cover could be developed that would reduce heat loss as efficiently as a normal wall, overall heat loss could be reduced by 10 percent. The curtain has already begun to show wear and without automatic operation it would be a weak link in the system. Other problems with this system include a buildup of moisture between the curtain and the window, and daily temperature fluctuations inside the house.

Overheating has not been a major problem. Fowlkes attributes this to the high angle of the summer sun; because summer sunlight strikes the surface at an angle greater than 60 degrees, much of it is reflected by the glazing.

From May through September the insulating curtain is not used. Because high temperatures could damage it, the curtain also is not used when the sun is shining. The thermal mass of the tubes effectively moderates the temperature in the house during the summer. Nevertheless, due to the lower angle of the sun during September and October, the home sometimes overheats. The problem can be alleviated by venting the warm air out of the house through existing windows and doors.

### BUILDING DETAILS

**Design type:** indirect gain
**Total floorspace:** 2,200 sq. ft.
**Heated floorspace:** 2,200 sq. ft.
**Window area** —
  South: 480 sq. ft.  East: 0
  North: 0  West: 0
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** water-filled tubes
**Auxiliary heating:** wood
**Insulation** —
  Ceiling: fiberglass to R-38
  Walls: fiberglass to R-19
  Floor: Fiberglass to R-19
  Foundation: rigid foam to R-11
  Windows: insulating curtain
**Cost of materials and labor:** $14,345 (solar heating system
**Cost per square foot:** unavailable
**Financing:** personal financing; partial financing through DNRC grant
**Microclimate** —
  Degree-days: 8,082
  Average summer temperature: 61°F
  Average winter temperature: 34°F

Bozeman

# Ritt Hoblitt

## BUILDING DESCRIPTION

An open hay field north of Bozeman is the site of Hoblitt's two-story, two-bedroom house. An integrated pit greenhouse provides indirect solar gain to this 1,360-square-foot, wood-frame structure. A truss-shed roof and vaulted ceiling permit free circulation of heated air throughout the house. Clerestory windows allow natural light to enter the home.

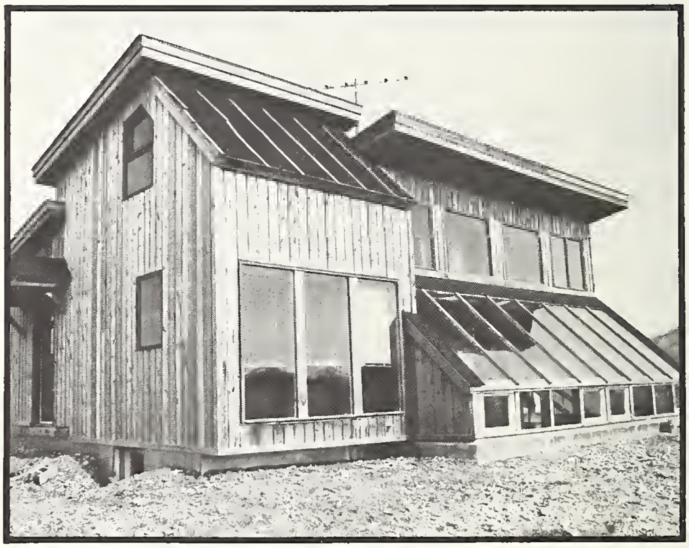
The outside of the home's 8-inch-thick concrete basement walls is insulated with 3 inches of rigid foam. The greenhouse foundation, set 5 feet below ground level, is insulated in a similar manner. The 2-by-6-inch exterior studwalls are insulated with 6 inches of fiberglass; the roof contains 9 inches of fiberglass. A 6-mil layer of polyethylene serves as an interior vapor barrier in the walls and ceiling.

## SOLAR SYSTEM

Double-glazed windows form the roof and walls of the pit greenhouse. This design allows sunlight to strike heat-storing water tubes and a masonry thermal mass, incorporated into the home as an open"common wall" between the greenhouse and living space. Four 20-foot, corrugated steel water tubes, 1½ feet in diameter, rest on a concrete footing pad. These tubes, along with the 210 cubic feet of sand-filled masonry block surfaced with dark stone, store heat for the greenhouse and adjacent living space. The masonry mass doubles as a chimney flue for a Vigilant® woodstove and as a plenum for blowing the warmer air from the ceiling to the floor. Light passing between the water tubes illuminates the living space. White greenhouse walls evenly reflect light for growing plants.

A small, south-facing den gains heat from a window seat consisting of three 55-gallon blackened steel barrels. The window seat, located just inside a row of vertical double-glazed windows, is framed on the north sides with wood lattice, which permits stored heat to reradiate into the room. This bench also provides a surface for growing plants.

The home is cooled convectively by opening two casement windows in the clerestory and four windows in the bottom of the south greenhouse wall. Three small windows in the basement can be opened to channel cooler air through the greenhouse as the warm air rises and escapes through the upper clerestory vents. Windows on the north, as well as a steel thermal door between the greenhouse and the outside, can be opened to further increase cross-ventilation.



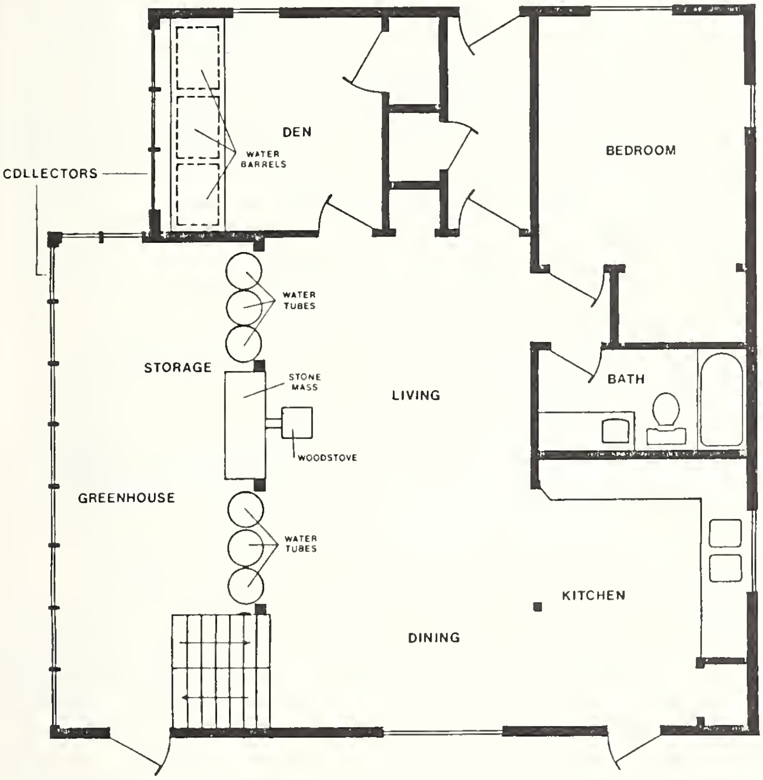
## MAINTENANCE AND LIVABILITY

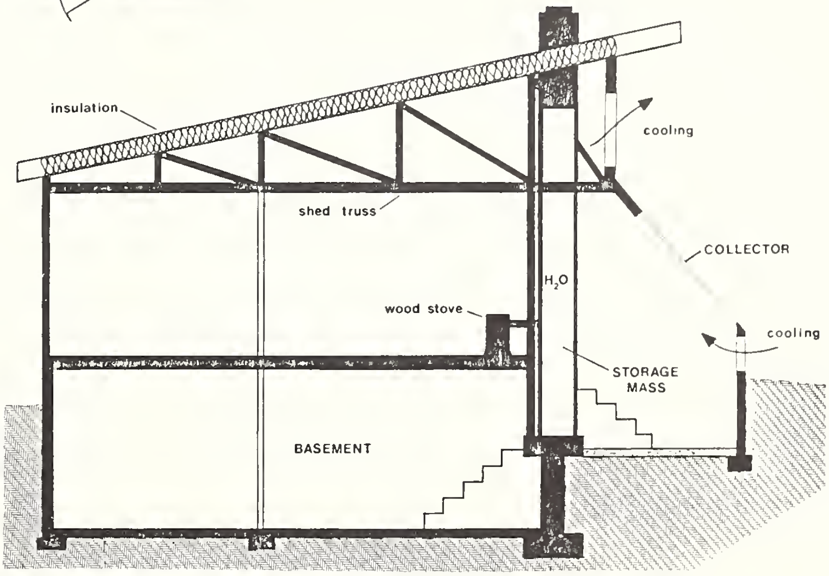
Careful attention to vapor barriers, insulation, and weatherization has helped to increase the effectiveness of the home's passive design features. The combined masonry and water heat-storage system helps to retain heat and reduce temperature fluctuations in the home.

The Hoblitts monitored temperatures in the greenhouse, living space, and water storage tubes and found temperature fluctuations of 9°F between the greenhouse and living area. Indoor winter temperatures range from a low of 62°F in the evening to an average of 69°F during the day. During the mild winter of 1980-81, the Hoblitts burned about two-thirds of a cord of wood to supplement solar heating. Electric baseboard backup heat was not needed. Heat loss, particularly in the greenhouse, could be reduced by adding thermal curtains. Overall, the solar performance of the house has surpassed both the designer's and the owners' expectations.

## BUILDING DETAILS

**Design type:** direct/indirect gain
**Total floorspace:** 2,260 sq. ft.
**Heated floorspace:** 1,360 sq. ft.
**Window area** —
South: 364 sq. ft. East: 28 sq. ft.
North: 16 sq. ft. West: 21 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** 10 degrees east of south
**Glazing angle:** 45 degrees
**Thermal storage:** water, rock, masonry
**Auxiliary heating:** wood, electric baseboard
**Insulation** —
Ceiling: fiberglass to R-32
Walls: fiberglass to R-19
Floor: none
Foundation: rigid foam to R-16.5
Windows: none
**Cost of materials and labor:** $42,500
**Cost per square foot:** $19
**Financing:** owner
**Microclimate** —
Degree-days: 8,082
Average summer temperature: 61°F
Average winter temperature: 34°F





## Bozeman

# George Mattson

George Mattson of Bozeman used $3,300 of an $8,000 Renewable Energy Program grant awarded in July 1977 to incorporate a passive solar heating system into his new home. Details of the active air system developed by Mattson are reported in Volume I of the *Montana Sunpower* series. The passive system was to be only one component of Mattson's complete heating system, which also includes active air solar collection, an electric furnace, and wood heating. For information or an appointment to visit the Mattson home, contact Mattson at 109 East Main, Bozeman, MT 59715; telephone 587-1240.

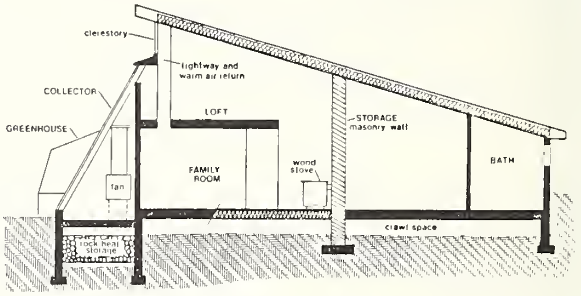
## BUILDING DESCRIPTION

The two main components of Mattson's passive solar system are a row of clerestory windows and a masonry heat-storage wall. The clerestory windows were installed in a row along the top of the south-facing wall, above the home's active solar collector bank. These vertical windows allow sunlight to strike the storage wall near the center of the house.

The windows, which cover 136 square feet, allow light to strike near the top of the storage wall in December and near the middle of the wall in February and October. An overhanging roof eave blocks sunlight in June. The 13 clerestory windows are separated by wall supports and a skylight that illuminates an inside loft area. All windows are double-glazed.

Several design features increase the system's heating potential. The masonry storage wall, for example, extends at a slight curve through the middle of the house. This design allows passive heat to be distributed throughout the house. Also, a fireplace and the flue pipe for the home's wood stove were built into the wall to heat the wall directly. Heat can be conducted from the flue to the storage wall.

The 288-square-foot reinforced masonry-block wall, which rests on a 3-foot-wide, 10-inch-thick concrete slab footing and a concrete-block foundation, provides some structural support for the rafters. Vents, 8 inches square, were built into the wall near the roof to allow air to circulate within the home. A natural stone facade enhances the wall's appearance and increases its heat-storing capacity.



## MAINTENANCE AND LIVABILITY

The Mattson home was monitored as part of the performance monitoring program funded by DNRC's Renewable Energy Program. Results of the monitoring are available to the public.

Mattson's experience is particularly instructive because the home is equipped with both active and passive solar space-heating systems. Although it is difficult to determine the amount of heat contributed by each system, Mattson believes that this relatively small-scale system effectively shows passive solar heating to be superior to active solar heating—passive features are nearly trouble-free and they perform efficiently.

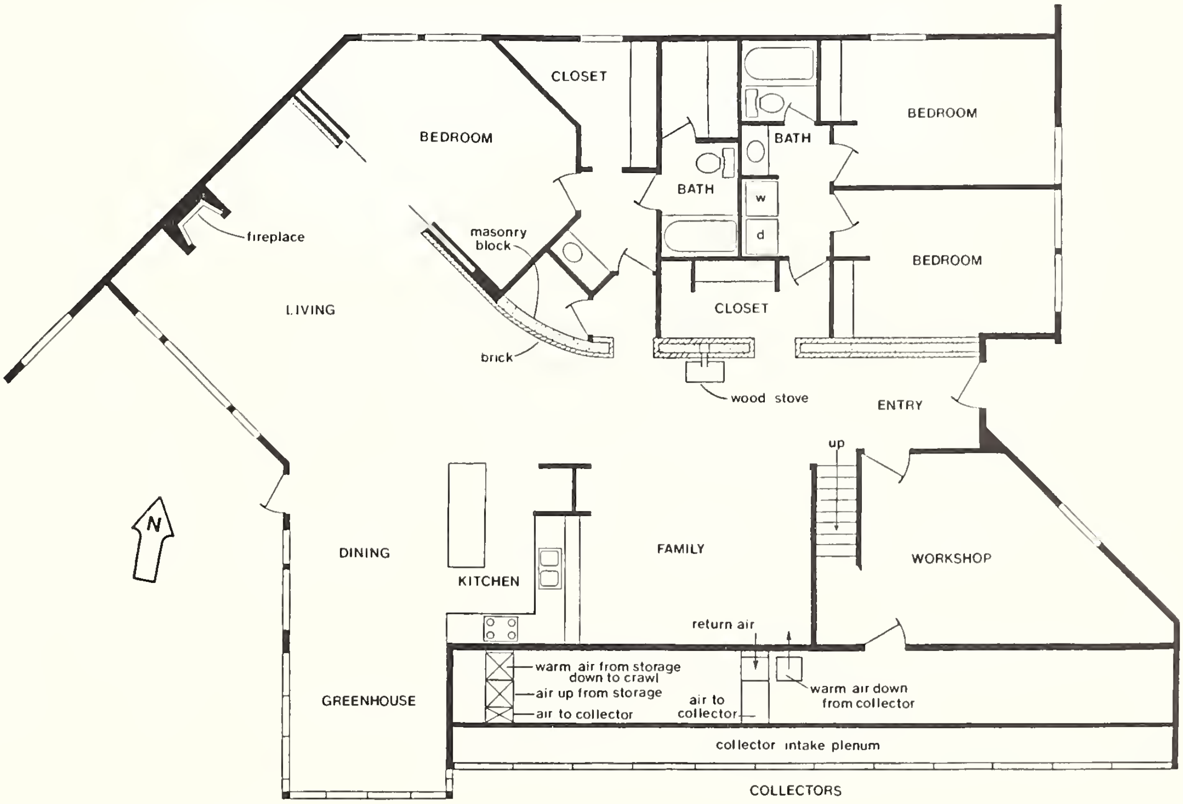
With the assistance of the two solar systems, Mattson has reduced the annual heating costs for his large home to $38 for natural gas and the cost of wood for his stove and fireplace. Mattson believes that the storage wall and windows enhance the beauty of his home while producing usable heat.

## BUILDING DETAILS

**Design type:** indirect gain
**Total floorspace:** 3,400 sq. ft.
**Heated floorspace:** 3,000 sq. ft.
**Window area** —

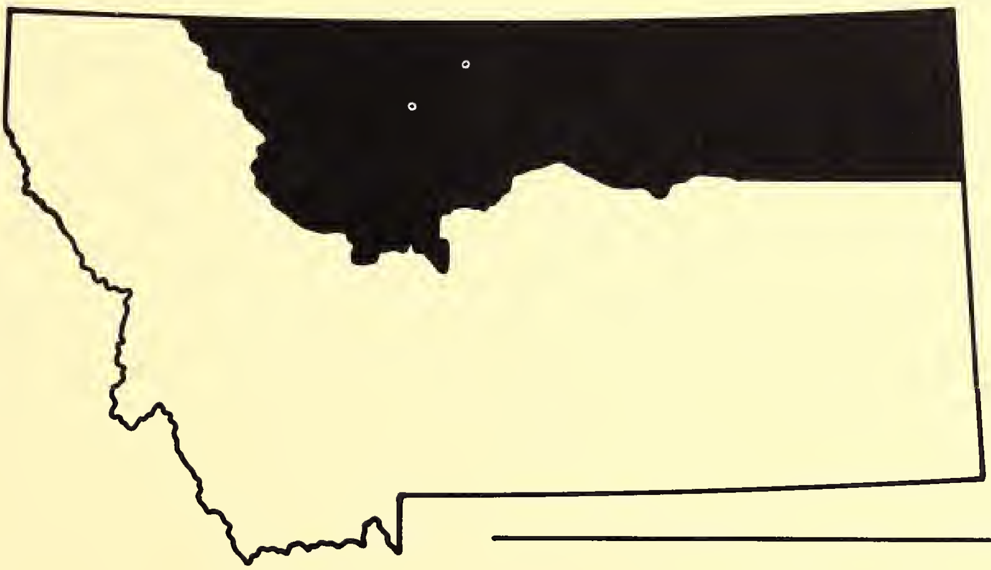
| | |
|---|---|
| South: 136 sq. ft. | East: 34 sq. ft. |
| North: 22 sq. ft. | West: 34 sq. ft. |

**Glazing:** two layers of glass
**Glazing orientation:** 5 degrees east of south
**Glazing angle:** vertical
**Thermal storage:** masonry
**Auxiliary heating:** wood
**Financing:** conventional loan; Renewable Energy Grant ($8,000)
**Microclimate** —
Degree-days: 8,082
Average summer temperature: 61°F
Average winter temperature: 34°F



# ZONE III

## Northeastern Montana



# The Land And Its Climate

The eastern front of the Rocky Mountains forms the western boundary of this zone, which extends some 600 miles east to the North Dakota border. This is a "continental" climatic zone, characterized by an abundance of sunshine, light rainfall, moderate winds, summer and winter temperature extremes, and large daily temperature changes. The area is bounded on the north by the Sweet Grass Hills, rising to 7,000 feet, and on the south by the Highwood Mountains. This high, rolling plain is interrupted by occasional, solitary buttes, by two isolated mountain ranges—the Bear Paws south of Havre and the Little Rockies south of Malta—and by coulees winding down to the rivers flowing eastward from the Continental Divide—the Teton, the Milk, and the Marias.

The Rocky Mountain foothills and frequent chinook winds, blowing along the eastern slope of the divide, temper the climate in this area. Temperatures at Cut Bank, a town commonly in the path of these chinooks, often rise dramatically as a result of these winds; the town experiences above freezing temperatures on the average of fifteen days each January. Chinook winds have been recorded at speeds exceeding 80 miles per hour and have been known to increase the ambient air temperature as much as 50°F in a matter of hours.

East of Havre a more typical continental climate predominates. The eastern part of this zone has an average winter temperature of 14.5°F. Occasionally, subzero temperatures and blizzard conditions are relieved by the warm chinook winds common along the Rocky Mountain front. Temperatures of 80° to 90°F occur regularly throughout the summer, although evenings are usually cool.

Temperature extremes are common in the eastern two-thirds of this zone. Westby has the coldest average winter temperature of any Montana town—9.9°F for December through February—while Glendive boasts the state's highest recorded temperature—117°F.

Yearly precipitation averages between 10 and 15 inches throughout this zone, with the largest percentage falling from May through July. Autumn is the driest season, followed by winter; average snowfall varies from about 30 inches in the east to 45 inches on the zone's western edge. Although snowfalls are generally light, strong northwesterly winds frequently cause drifting across the open prairie.

The northern plains area is subject to extremes in precipitation as well as temperature. During one 24-hour period, Circle received a record 11.5 inches of rain. The same area experiences periodic droughts. Damaging summer hail occasionally threatens crops in this zone.

Although winters in this zone normally are frigid, the sun shines regularly. The northern plains region receives an average of 52 percent of the sunshine possible during the heating season.

### CLIMATE SUMMARY

A) 50-55% possible sunshine* during heating season; low to moderate cloud cover

B) Insolation on vertical south wall during average heating season:
Cut Bank — 902 Btu/ft$^2$/day
Glasgow — 868 Btu/ft$^2$/day

C) 8,505 annual degree-days averaged over all stations in zone

D) Wind — moderate to high speed. Chinooks are frequent in western half of this zone; strong, cold winter winds are likely throughout zone

E) Temperatures:
Average January temp. (F°) for zone: 15.6
Average August temp. (F°) for zone: 67.2

* The actual hours of sunshine divided by the possible hours of sunshine, expressed as a percentage.

Sources: *WSUN #8 Montana Solar and Weather Information, Montana Solar Data Manual, Montana Renewable Energy Handbook.*

# Design Criteria For Zone III

Building designs in this zone must address the temperature extremes common in this region and the strong winds that cause conductive and infiltrative heat loss. A reliable supply of sunshine is available throughout most of the year, so the potential for solar space heating is good. Unfortunately, this supply of sunshine also increases the potential for overheating in the summer.

## ELEMENTS OF DESIGN

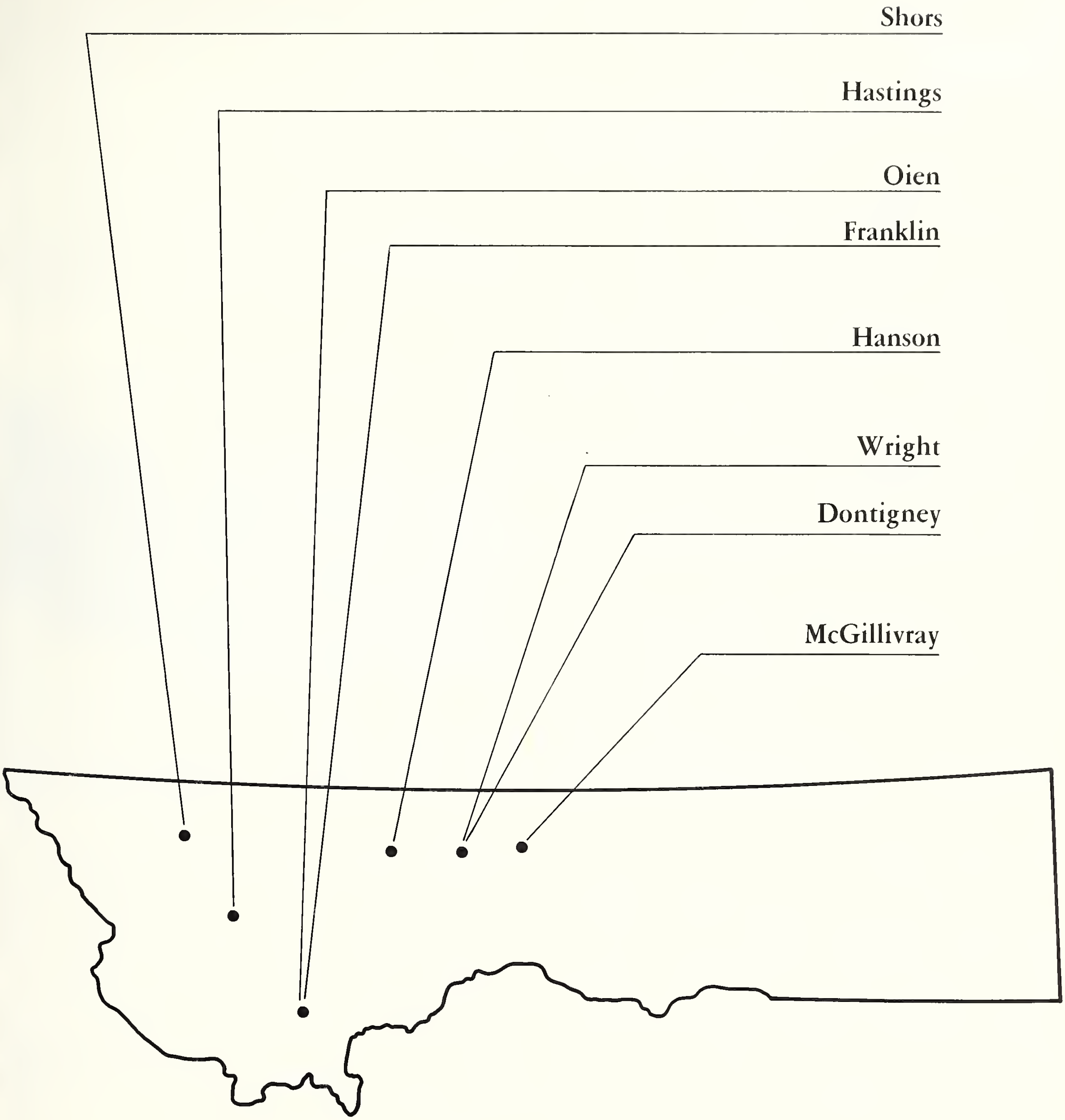
Special design considerations for this climate zone would include using insulation at or above current FHA standards—a minimum of R-38 in the roof and R-19 in the walls—to reduce winter heat loss and summer heat gain. Also, berming earth around the outside walls and using exterior rigid foam to insulate the foundation will help to reduce conductive heat loss through the concrete, as well as to reduce the exposed wall area. The earth-sheltered design can be enhanced by incorporating a walkout or daylight basement on the south to increase solar gain and thermal storage capacity. Vestibule-airlock entryways are recommended to reduce the amount of heat lost when entering and leaving the building. Steel thermal doors with magnetic weatherstripping also are recommended to reduce infiltration.

East and west windows or vents help to increase summer ventilation. This is an important design feature where summers are usually hot and humid. Trees planted on the north and west will help deflect prevailing winter winds, while deciduous trees planted on the south can shade glazing from direct sunlight during the spring, summer, and fall.

Of course, standard siting and design rules for solar homes also should be followed: a building should be oriented along an east-west axis; south-facing windows should be double-glazed and insulated with thermal shutters or curtains; roof overhangs should be designed to shade windows from the hot summer sun; and windows should be limited on the north, east, and west sides of the structure.

## GLAZING AND THERMAL STORAGE

According to the Balcomb *Passive Solar Design Handbook* discussed in the design criteria section for Zone I, a south-facing window area that represents 24 to 49 percent of the total floor area of a home in Cut Bank can be expected to reduce the annual heating load of that home by 22 to 33 percent, or by 62 to 81 percent if R-9 nighttime insulation is used. In Glasgow, a south-facing window area that represents 25 to 50 percent of the total floor area of a home can be expected to reduce the annual heating load of that home by 30 to 35 percent, or by 55 to 75 percent with R-9 nighttime insulation.


Shors
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Cut Bank

# Richard and Ann Shors

## BUILDING DESCRIPTION

The Shors' home east of Cut Bank is set into a south-facing hillside overlooking open grassland. The hill and an attached garage on the north help to protect the home from cold winter winds spilling over the Continental Divide. A daylight basement and solarium on the main floor provide extensive south glazing to collect solar heat.

This three-bedroom, manufactured log home sits on concrete foundation walls insulated on the outside with 1-inch molded polystyrene panels. The rim joist was carefully insulated with 6 inches of fiberglass.

The exterior log walls are interlocked by a double tongue and groove. The spaces between the logs are filled with fiberglass, and the exterior log seams are sealed with silicone caulk to reduce moisture penetration and infiltration. The inner sides of the perimeter walls are furred out with 2-by-4-inch studs, insulated with 3½ inches of fiberglass, and finished with sheetrock. The roof of the home is well insulated to help retain heat; 12 inches of fiberglass and 4 inches of cellulose fill the attic space.

## SOLAR SYSTEM

The 6-by-34-foot solarium, which contains more than 100 square feet of triple-pane glazing, is separated from the Shors' living room by a 3-foot-high concrete block wall that supports a 2-by-4-inch studwall containing windows. Heat is distributed convectively through sliding glass doors and opening windows between the solarium and the living space. The block wall, filled with sand and faced on the interior with red brick, stores heat for use in the house and solarium. The dark ceramic-tile floors in the kitchen and solarium store additional heat.

An exposed, 4-inch-thick concrete floor in the basement stores heat for the lower floor. Heat losses through the 252 square feet of southern glazing are reduced by insulated curtains. A roof overhang shades the glazing in the summer to prevent overheating. Casement windows on the east and west sides of the home can be opened to catch summer breezes and promote cross-ventilation.

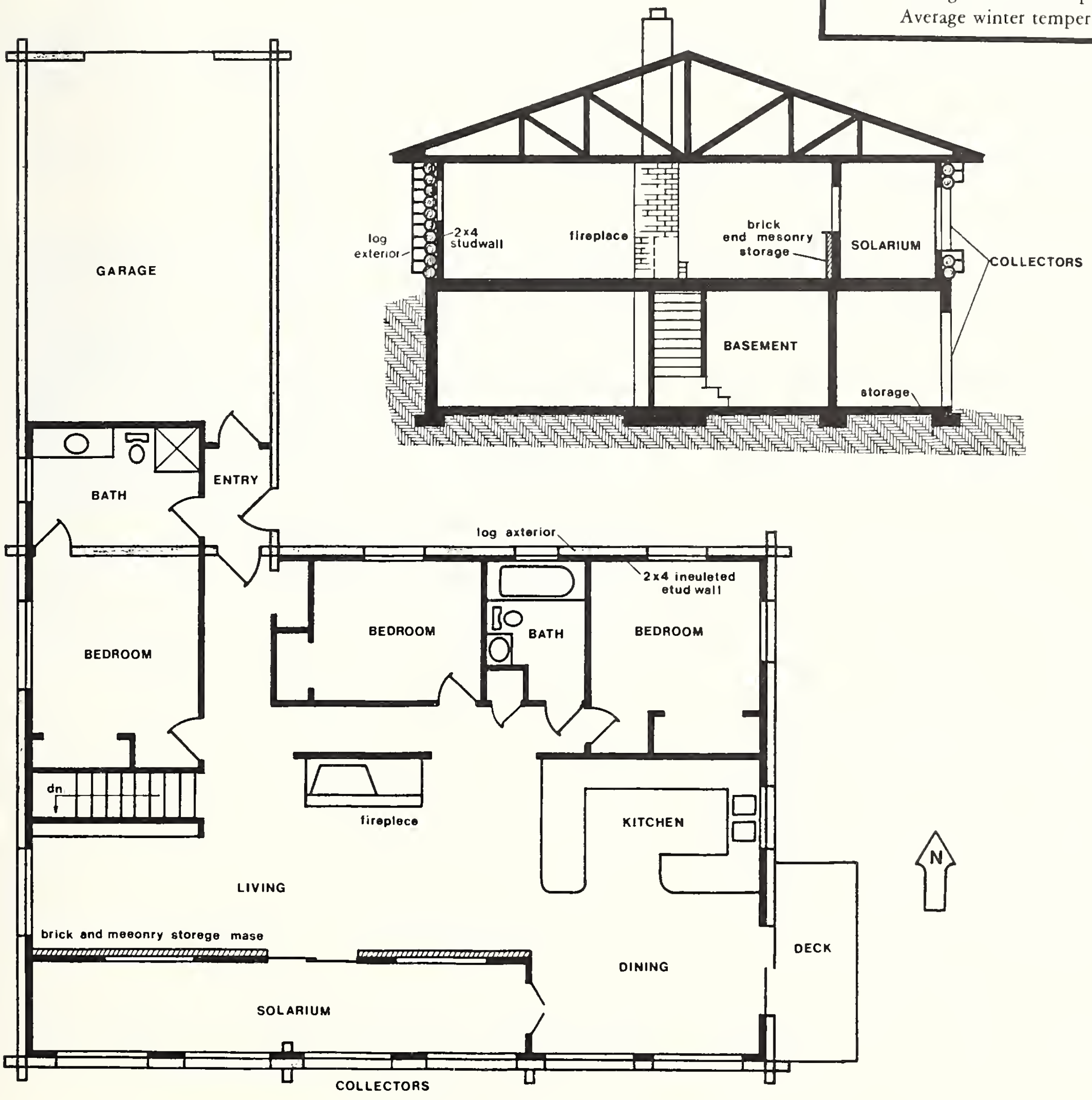
## MAINTENANCE AND LIVABILITY

The thermal efficiency of the Shors home is a direct result of its tight construction, adequate insulation, and extensive southern glazing. Siting the garage and the vestibule entry on the north helps limit infiltration of cold air and subsequent heat losses. During the winter, without auxiliary heating, temperatures in the home have never fallen below 55°F, and on sunny winter days the solarium often reaches temperatures of 85° to 90°F. Electric baseboard heaters and a centrally located fireplace provide backup heating; neither the fireplace nor the heaters are used extensively. Good convective air circulation, an important design consideration in all passive buildings, has been achieved with the open floor plan. Summer temperatures in the Shors home have never exceeded 80°F.

The owners recommend several minor changes in design and construction. Increasing the height of the foundation and adding more berming to the north wall would reduce heat loss through the wall's surface and increase the home's thermal storage capacity. Additional thermal mass could be gained by relocating the fireplace to catch more of the sun's radiation. Also, the drying and settling of the log walls, particularly around the windows, has been a minor problem. In general, however, the Shors are pleased with the performance of their passively heated home. They consider window insulation an important factor in reducing nighttime heat loss from the solarium.

## BUILDING DETAILS

**Design type:** direct/indirect gain
**Total floorspace:** 2,700 sq. ft.
**Heated floorspace:** 2,000 sq. ft.
**Window area** —
  South: 252 sq. ft. East: 60 sq. ft.
  North: 22 sq. ft. West: 42 sq. ft.
**Glazing:** three layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** masonry and concrete
**Auxiliary heating:** electric baseboard
**Insulation** —
  Ceiling: fiberglass and cellulose to R-50
  Walls: fiberglass to R-19
  Floor: none
  Foundation: rigid foam to R-3.5
  Windows: insulated curtains
**Cost of materials and labor:** $85,000
**Cost per square foot:** $31
**Financing:** conventional loan
**Microclimate** —
  Degree-days: 8,963
  Average summer temperature: 59°F
  Average winter temperature: 31°F



Conrad

# David and Lavonne Hastings

## BUILDING DESCRIPTION

The south wall of the Hastings' four-bedroom, wood-frame farmhouse near Conrad is formed by an attached "pit greenhouse." The greenhouse, sunk about 3½ feet into the ground, opens into the living room through a sliding glass door. Two adjacent bedrooms along the south wall receive collected greenhouse heat through opening windows. A vestibule entry on the east and an attached garage on the north help buffer the living space from the elements.

The 560-square-foot greenhouse is framed with 2-by-6-inch uprights attached by gussets to short rafters, which extend from the south shed roof of the house. The west wall of the greenhouse is insulated with 6 inches of fiberglass and covered with a vapor barrier on the inside; 1 inch of Thermax® covers the outside of the wall. The east wall is glazed with Lexan® .

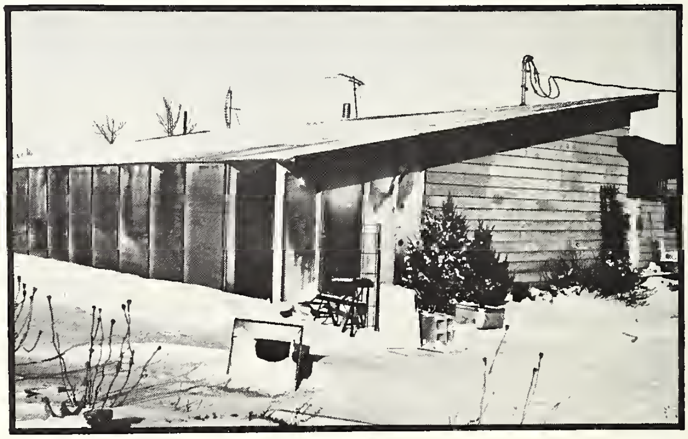
The 15-year-old house is framed with 2-by-4-inch studs insulated with 3½ inches of cellulose. The south shed roof contains 6 inches of cellulose and 2-inch polystyrene panels. The rest of the roof is insulated with 6 inches of cellulose. Both of the home's entryways have foam-core, steel doors with magnetic weatherstripping.

## SOLAR SYSTEM

Solar heat is collected through 662 square feet of double-glazed windows on the south wall and roof of the greenhouse. Heat also is gained directly through 125 square feet of windows on the south side of the house. Heat storage was increased by insulating the greenhouse foundation wall with 3-inch polystyrene panels and by filling the greenhouse pit with 107 tons of moist dirt. This earthen mass is insulated from below by 2-inch polystyrene panels.

To increase the amount of heat stored in the floor, a small fan was mounted at the apex of the greenhouse roof to blow warmed air into a series of PVC pipes buried in the soil. In this manner, the 4-inch-diameter pipes heat the greenhouse floor from within. Heated air from the greenhouse moves by convection into the living space of the house through the preexisting doors and windows in the south wall. Windows in the south foundation wall allow cooler air from the basement to enter the convective air cycle and be heated in the greenhouse during the day.

Thermax® and polystyrene shutters, manually inserted on the inside surface of the greenhouse roof and wall glazing, help to reduce nighttime heat loss during the winter and overheating in the summer. The greenhouse is cooled by opening the west window and east door of the greenhouse to catch prevailing breezes. Overheating has not been a problem.



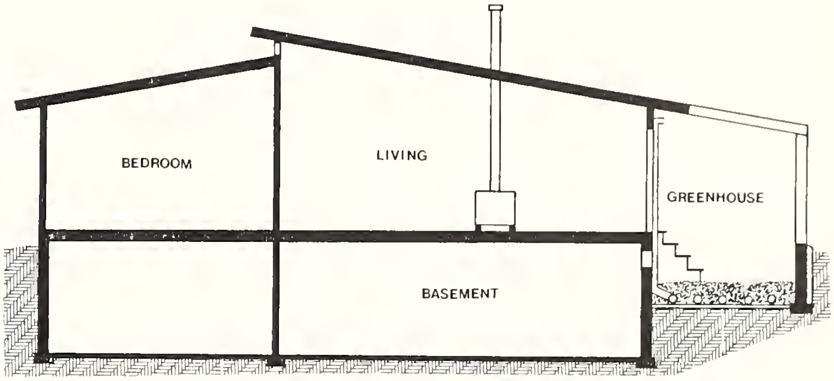
## MAINTENANCE AND LIVABILITY

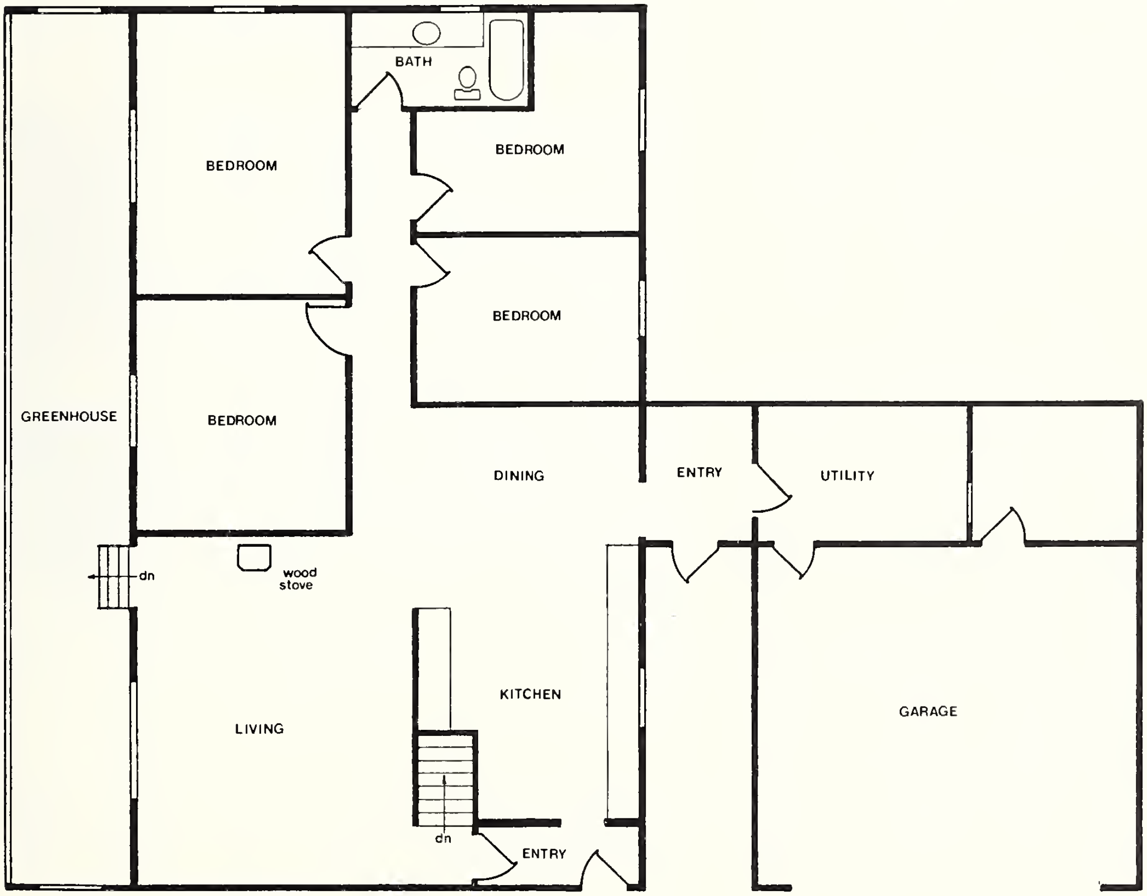
The Hastings retrofit has offset space heating fuel costs while providing an area for growing root crops year round. Winter temperatures in the house fluctuate between 60° and 72°F. During the winter of 1979-80, approximately two cords of wood were burned for backup heating. A gas furnace occasionally provided supplemental heat.

Winter greenhouse temperatures generally range from 45° to 70°F, although on extremely cold nights the temperature has dropped below 32°F. Temperature fluctuations could be reduced by adding more thermal mass to the greenhouse.

## BUILDING DETAILS

**Design type:** Solar greenhouse
**Total floorspace:** 2,630 sq. ft.
**Heated floorspace:** 2,070 sq. ft.
**Window area** —
  South: 617 sq. ft.  East: 15 sq. ft.
  North: 56 sq. ft.  West: 25 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** masonry, soil
**Auxiliary heating:** wood, gas furnace
**Insulation** —
  Ceiling: fiberglass and rigid foam to R-26
  Walls: fiberglass to R-11
  Floor: none
  Foundation: none
  Windows: rigid foam shutters
**Cost of materials and labor:** $6,000
**Cost per square foot:** $11
**Financing:** conventional loan
**Microclimate** —
  Degree-days: 8,195
  Average summer temperature: 59°F
  Average winter temperature: 23°F





Conrad

# David Oien

## BUILDING DESCRIPTION

Oien's three-bedroom, two-story, earth-sheltered home west of Conrad was sited to protect it from the climatic extremes of northern Montana. The effects of the hot summer sun and winter winds are moderated by two rows of ash trees on the south and west. Seven feet of bermed earth protects the north wall and parts of the east and west sides of the house.

The outside surfaces of the 8-inch-thick concrete foundation walls are coated with asphalt emulsion and covered by 6 inches of polystyrene panels. The shed roof is framed with T.J.I.® structural wood joists and insulated with 12 inches of fiberglass. Cross-hatching was used on the south wood-framed walls. The 2-by-6-inch studwalls were filled with 6 inches of fiberglass and covered with a 6-mil polyethylene vapor barrier. Horizontal 1-by-4-inch boards then were nailed to the studs before the sheetrock was attached. This technique allowed a 1-inch space to be left in the wall so that electrical wiring could be installed without puncturing the vapor barrier.

## SOLAR SYSTEM

Double-glazed windows on both levels of the south wall provide 180 square feet of collection area for direct solar gain. A 3-inch-thick poured concrete floor, insulated from the ground by 2-inch polystyrene panels, provides thermal storage, as do the home's walls and Russian fireplace.

Three-inch-thick bricks cover the concrete floor and line the inside of the north wall on the lower floor. A 4-inch air space exists between this brick wall and the concrete north wall of the house.

Isolated gain space heating is provided by 324 square feet of homemade, thermosyphoning air collectors. These collectors, mounted on the windowless sections of the south wall, are separated from the outside wall by a 1½-inch air space. Each collector is vented to the inside through two 3½-by-20-inch vents, one at the top of the collector and one at the bottom. Cool floor air enters the collectors through the lower vents, rises by convection as it is heated by sunlight, and returns to the house through the upper vents. Vent doors prevent backdrafting at night.

Additional solar gain occurs in a 180-square-foot, earth-bermed greenhouse attached to the southeast end of the home. Both the vertical south wall and gable roof of the greenhouse incorporate 59 square feet of double glazing. The remaining north and east walls of the greenhouse consist of cement-filled blocks, insulated on the outside with 6-inch polystyrene panels. The outside of the south foundation wall is separated from the surrounding earth by 2 inches of rigid foam. The two insulated walls and a 4-inch concrete floor give the greenhouse a total thermal storage area of 160 cubic feet.

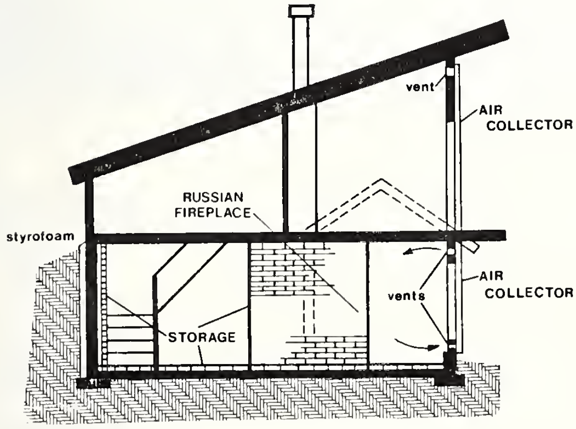
A homemade Russian fireplace in the center of the house provides backup heating and an additional 96 cubic feet of thermal mass. This highly efficient fireplace contains a long, narrow firebox surrounded by red brick. The fireplace is designed to burn fuels quickly at very high temperatures; the heat produced is transferred to the large masonry mass of the fireplace through a sinuous flue pattern. Combustion air for the fireplace and wood cookstove comes through an 80-foot-long, 6-inch-diameter PVC "earth tube" that collects heat from the surrounding earth to preheat outside air before it enters the home. This pipe is buried horizontally 8 to 10 feet below ground until it emerges at the intake. During February, when the outside temperature was -36°F, the temperature of the air entering the house through the tube was 50°F.

A 3-foot roof overhang and balcony help to shade and cool the house in summer. Also, east and west windows can be opened to increase cross-ventilation and catch prevailing winds.

## MAINTENANCE AND LIVABILITY

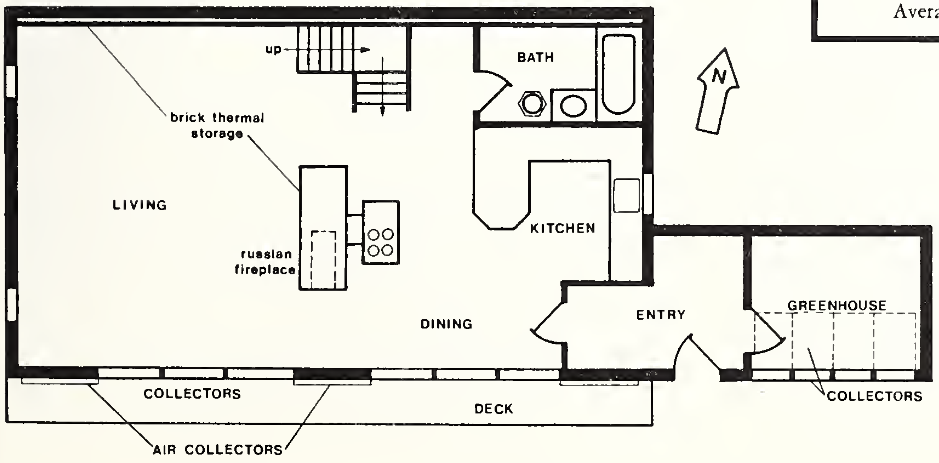
The earth-sheltered, passive solar design combined with the proper use of insulation creates a comfortable living environment year round. When left unattended with no backup heating and outside temperatures down to -25°F, the Oien house cooled to 48°F. Average winter temperatures in the house range between 52° and 68°F with some fireplace heating. During the summer, the house maintains a comfortable temperature of 68°F.

In retrospect, Oien recommends increasing the thickness of the exterior walls so that more insulation could be installed, and pouring a masonry floor for the upper level to provide additional thermal storage. Other recommendations include adding some form of night-time window insulation that could be operated more easily than the large 2-inch-thick polystyrene panels he now uses. The Oien design provides a comfortable, well-lighted living space at a cost lower than most conventional homes.



### BUILDING DETAILS

**Design type:** direct/indirect gain
**Total floorspace:** 2,196 sq. ft.
**Heated floorspace:** 2,016 sq. ft.
**Window area** —
  South: 180 sq. ft. East: 19 sq. ft.
  North: 0 West: 16 sq. ft.
**Glazing:** two and three layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** brick, concrete
**Auxiliary heating:** wood
**Insulation** —
  Ceiling: fiberglass to R-38
  Walls: fiberglass to R-19
  Floor: rigid foam to R-7
  Foundation: rigid foam to R-22
  Windows: rigid foam panels and insulating shades
**Cost of materials and labor:** $49,000
**Cost per square foot:** $22
**Financing:** Federal Land Bank
**Microclimate** —
  Degree-days: 8,195
  Average summer temperature: 63°F
  Average winter temperature: 26°F



Great Falls

# Gary Franklin

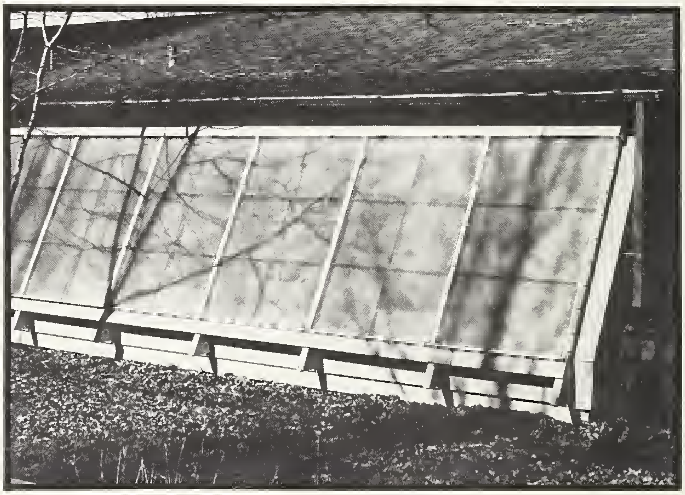
In 1977, Gary Franklin received a $5,000 grant from DNRC's Renewable Energy Program to attach a solar greenhouse to his existing home. Visitors are welcome at the Franklin residence. To arrange for a visit, contact Franklin at 4428 6th Ave. South, Great Falls, MT 59405; telephone 727-7661, or 761-0645 after 6 p.m.

## BUILDING DESCRIPTION

A 240-square-foot greenhouse was added to the three-bedroom, single-story Franklin home in 1977. Located in a 20-year-old subdivision in southeastern Great Falls, the Franklin retrofit takes advantage of the home's southern exposure to supplement conventional heating sources with solar heat. To ensure efficient use of this heat, Franklin added an additional 6-inch blanket of insulation to the home's attic before beginning the project.

A foundation was formed by setting 21 wooden piles on concrete footings buried 4 feet in the ground. Three 2-by-6-inch support beams were attached to the piles to support the greenhouse floor. These beams were joined by 1-by-8-inch lumber to form a rectangular frame. A crawl space beneath the greenhouse is filled with 12 inches of gravel. A polyethylene vapor barrier was placed over the gravel, followed by a layer of 2-inch-thick polystyrene panels and a layer of aluminum foil. A 1-inch airspace was left between the foil and the 1-by-6-inch tongue-and-groove flooring. The floor then was covered with another polyethylene vapor barrier and half-depth paving bricks for thermal storage.

The ceiling and three walls of the greenhouse were framed with 2-by-6-inch lumber and insulated with 4-inch rigid foam panels and 2-inch fiberglass batts. A large window with exterior shutters and manual vents was installed on the west end of the greenhouse; the east end contains two window vents and a door. The roof frame was mounted on a series of 2-by-8-inch support pieces that frame the south-facing glazed area. A conventional asphalt covering was placed on the roof.



## SOLAR SYSTEM

The south wall of the greenhouse is tilted and covered with a double glazing of Kalwall Sun-Lite® fiberglass panels. A series of vents at the bottom of the glazed area, along with screened windows and vents on the sides of the greenhouse, can be opened to prevent overheating. Insulated wooden panels cover the vents in winter to limit heat loss. Simple wooden planter boxes were placed on the floor along the length of the glazed wall.

Heat is collected through 144 square feet of double-layered Kalwall fiberglass; a 1½-inch airspace exists between the layers. The glazing in these prebuilt solar collection panels is attached to the framing with aluminum flashing. The brick tile floor and the planting beds provide 30 cubic feet of mass for storing heat.

Heat from the greenhouse circulates into the house through an existing door and windows. A small fan in the door increases the movement of air between the greenhouse and the living space. Air circulation is particularly important in the evening when heat from a Jotul Com-Fire® wood stove in the house supplements solar heat in the greenhouse. An existing natural gas furnace is set to fire at 60°F for further backup heating.

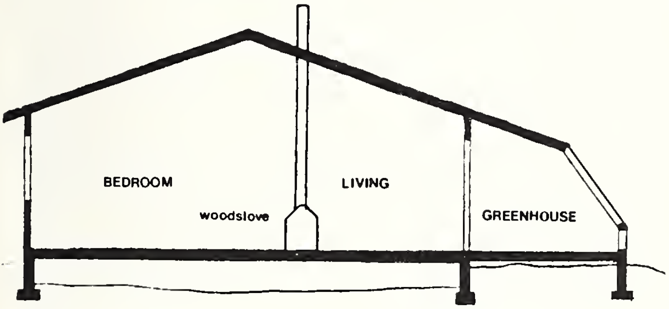
For greater efficiency, combustion air for the wood stove is drawn through several small holes drilled in the floor beneath the stove. This air, which comes from a crawlspace beneath the house, is circulated through the house, reentering the crawlspace through an access door in the floor of a bedroom at the far end of the house. This simple air circulation system effectively distributes stove heat throughout the house.

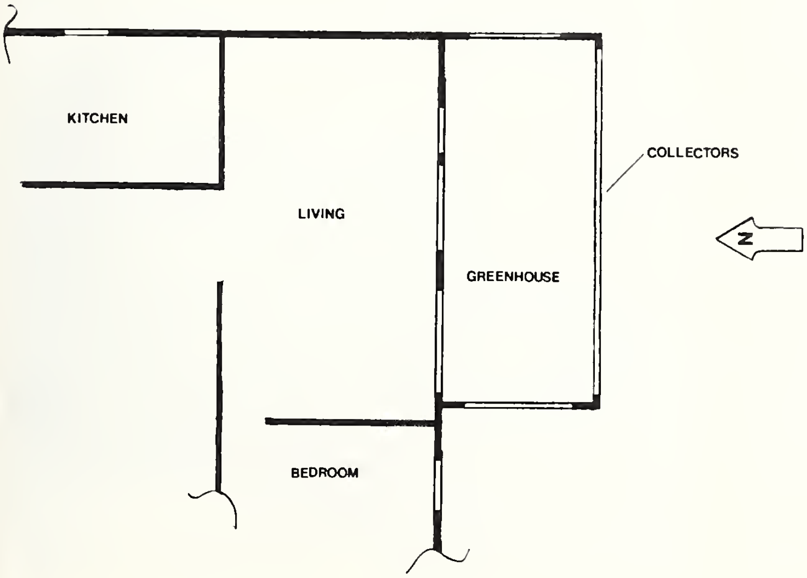
## MAINTENANCE AND LIVABILITY

The Franklin greenhouse has performed well when used properly. When the Franklins left their house in the care of another family during January, the monthly heating bill rose from $30 to about $70—which dramatically illustrates the importance of proper system operation. Temperature monitoring and proper manual operation of the windows, vents, fan, and window insulation are necessary for effective results.

Winter harvests of tomatoes, peppers, beets, and lettuce indicate that temperatures are adequate for producing food, and that enough light enters the greenhouse to ensure adequate plant growth. Despite the lack of glazing on the greenhouse roof and the presence of shade trees on the south, Franklin has grown vegetables in the greenhouse on a year-round basis. He is, however, considering adding skylights to the greenhouse roof to increase summer lighting.

Although actual system performance has not been documented by careful monitoring, design computations predict that the greenhouse will provide heat worth about $220 per year, based on 1978 natural gas prices. Franklin believes that food worth another $260 per year can be grown in the greenhouse. With this level of performance, he expects a payback period of about six years. This relatively short payback period can be attained partly because costs did not include interest, because no cost was assigned to firewood for the stove, and because labor costs for maintenance and construction were not included in payback calculations.





### BUILDING DETAILS

**Design type:** solar greenhouse
**Total floorspace:** 1,150 sq. ft.
**Heated floorspace:** 1,150 sq. ft.
**Window area** —
  South: 168 sq. ft. East: 10 sq. ft.
  North: 40 sq. ft. West: 42 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** 65 degrees
**Thermal storage:** brick, soil
**Auxiliary heating:** wood, natural gas furnace
**Insulation** —
  Ceiling: fiberglass and cellulose to R-32
  Walls: fiberglass to R-8
  Floor: none
  Foundation: none
  Windows: none
**Cost of materials and labor:** $5,000 (greenhouse)
**Cost per square foot:** $22 (greenhouse)
**Financing:** Renewable Energy Program grant
**Microclimate** —
  Degree-days: 7,652
  Average summer temperature: 64°F
  Average winter temperature: 33°F

# J. Levi and Diane Hanson

In 1978, J. Levi Hanson, a farmer in Gildford, received a $6,446 Renewable Energy Program grant to partially finance an 800-square-foot greenhouse addition to his existing residence, a two-story hotel built in 1919. To arrange a visit, contact Hanson at Box 1776, Gildford, MT 59525; telephone 376-2542.

## BUILDING DESCRIPTION

The former hotel structure was sound, having been built on a 30-inch, poured concrete and stone foundation. The Hansons remodeled the interior, removing partitions and lathe plaster walls to reinsulate with fiberglass and rigid foam to a value of R-25. The roof of the building contains 6 inches of fiberglass insulation. Convective air movement throughout the house is facilitated by an open floor plan.

## SOLAR SYSTEM

The 800-square-foot greenhouse addition is glazed with corrugated Filon® , a translucent fiberglass glazing. The south glazing for the greenhouse is supported by 24-foot-long gable trusses, set on 2-foot centers and leaning against the south wall of the house at a 70-degree angle.

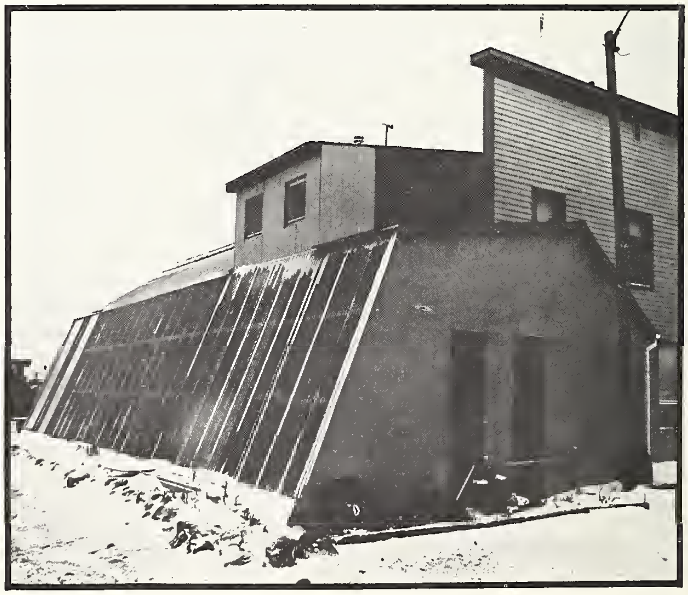
Heat collected through 1,400 square feet of glazing is stored in 350 tons of rock in the greenhouse. Hanson buried 8-inch perforated tubes in the rock bed so that heat, pushed into the tubes by a small fan, could be distributed more evenly in the thermal mass. Heated air moves from the greenhouse to the living space through windows in the south wall of the house. This heat is distributed by a 36-inch circulating ceiling fan in the living room.

Double-glazed windows with Window Quilt® thermal curtains are used throughout most of the home to help reduce evening heat losses.

## MAINTENANCE AND LIVABILITY

Few problems were encountered in constructing this system; its design was fairly simple and most materials were available locally. Hanson said his major problem was finding a workable, movable insulation system at a reasonable price. Estimates for such a system ran as high as $9,000, although he finally obtained one from Automated Devices Corporation for less than $2,000. The main component of the system is a curtain made of Foilon® a reflective, nylon-mesh material.

Lack of windbreaks exposed the greenhouse to summer windstorms with southwesterly gusts of up to 80 mph, including one clocked at 135 mph. These severe winds played havoc with the Filon® sheets; in several cases the upper west portion of the sheets was severely damaged. Hanson tried holding the sheets in place with metal straps. Because this solution did not prove effective, he has since decided to replace this portion of the Filon® with prefabricated fiberglass panels from a commercial domestic hot water heating system.



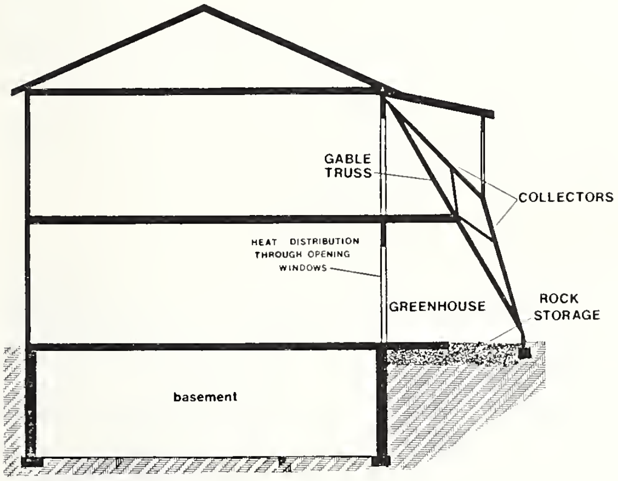
The Hansons are satisfied with the performance of their greenhouse. Although no monitoring data are yet available, the Hansons estimate annual savings of $500-$600 in heating costs, even with the addition of about 900 square feet of floor space.

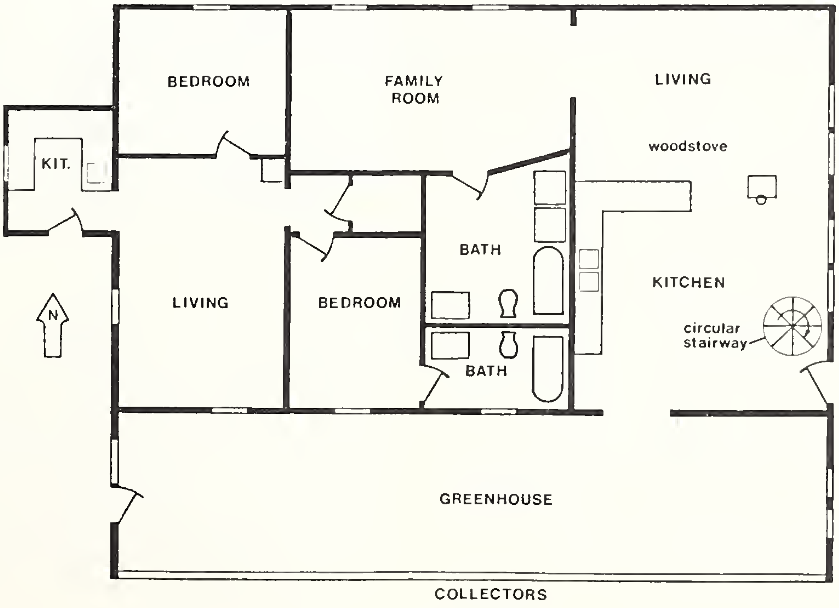
Because high winds hampered the performance of the original vent system, Hanson is redesigning a chimney venting system for the west end. Also, in order to cut heat loss in the greenhouse, he plans to install 1,400 square feet of Foilon® to the underside of the greenhouse trusses. This curtain should help lower summer temperatures in the greenhouse, which have been high despite the ventilation provided by east-west doors.

Although the temperature outside hovered around 10°F during an on-site interview in February, the living space seemed evenly heated on both levels. Hanson is considering adding a water heat-storage system to reduce daily temperature fluctuations in the greenhouse.

## BUILDING DETAILS

**Design type:** solar greenhouse
**Total floorspace:** 3,400 sq. ft.
**Heated floorspace:** 2,600 sq. ft.
**Window area** —
  South: 1,520 sq. ft. East: 80 sq. ft.
  North: 90 sq. ft. West: 40 sq. ft.
**Glazing:** two layers of glass (house), Filon® (greenhouse)
**Glazing orientation:** south
**Glazing angle:** 70 degrees
**Thermal storage:** rock, concrete
**Auxiliary heating:** wood, natural gas furnace
**Insulation** —
  Ceiling: fiberglass to R-19
  Walls: fiberglass and rigid foam to R-20
  Floor: none
  Foundation: none
  Windows: insulated shades
**Cost of materials and labor:** $50,000
**Cost per square foot:** $15
**Financing:** owner financed, along with Renewable Energy Program grant ($6,446)
**Microclimate** —
  Degree-days: 8,213
  Average summer temperature: 65°F
  Average winter temperature: 33°F





## Havre

# Brian Wright

## BUILDING DESCRIPTION

Built in a subdivision south of Havre, the Wright home overlooks open, rolling prairie foothills. The site has a good solar exposure, although a small butte to the east eclipses some early morning sunshine.

This two-story, three-bedroom home features an envelope design. The envelope is a product of the home's double-walled construction; a continuous path for air distribution exists in the tempered climate between the living space and the outer shell of the home. Both the inside and outside walls are insulated to reduce heat loss. Heat from a solarium, which runs the length of the house and is open to the second story, warms the enclosed air space, or plenum, during the day.

An interesting feature of the Wright house is its treated wood foundation. All of the wood in the 4-foot high, 2-by-6-inch wood foundation wall was pressure treated with a copper-arsenate-based salt solution. This wood wall sits on a treated 2-by-8-inch footing plate which rests on a gravel footing. Half-inch treated plywood was nailed to the foundation studwall with aluminum nails. The inside of the foundation wall is insulated with 4 inches of wet-spray cellulose. Six mil polyethylene sheeting prevents water from entering the foundation and crawlspace.

The home's 2-by-6-inch exterior walls are insulated with 5 ½ inches of insulation and sheathed with ¾-inch Thermax® panels. Steel bracing straps were nailed to the studs to give the walls diagonal strength, although Wright believes greater strength could have been achieved by sheathing the walls with ½-inch CDX-grade plywood. The north wall of the solarium, insulated with 6 inches of fiberglass, is double-framed with a 12-inch-wide plenum between the 2-by-6-inch exterior wall and the 2-by-4-inch interior wall. The walls are insulated with fiberglass to values of R-19 and R-11, respectively. The plenum is open to the crawl space under the main floor, as well as to the attic above the house. The interior surface of all perimeter walls is lined with a 6-mil polyethylene vapor barrier.

## SOLAR SYSTEM

The house was designed so that air heated in the solarium would rise convectively and circulate through the plenum that envelops the house. The double north wall allows the heated air to vent through the crawlspace under the house. Envelope designer Tom Smith of Nevada calls this the ''geo-solar'' approach, since warmed air in the plenum comes into contact with the thermally constant earth beneath the house. In such a design, the living space is protected from outside temperature extremes by a moderately tempered blanket of air. This isolated gain design allows the Wrights to control living space temperatures by opening and closing windows between the solarium and the home's interior.

## MAINTENANCE AND LIVABILITY

Double-walled construction greatly reduces heat loss from the living area. The inner walls are surrounded by a temperate air plenum that provides a buffer between the living area and the outside. In an effort to maintain the temperate airspace, the Wrights installed an air lock entryway with urethane foam-filled steel entry doors and magnetic weatherstripping. Windows on the east, north, and west sides of the home represent only 20 percent of the home's total glazed area, thus reducing potential heat loss. A Hurricane wood stove and electric baseboard heaters provide backup heating.

Winter temperatures in the interior living space range from a low of 60°F to a high of 70°F. Temperatures in the solarium, however, fluctuate much more, from lows of 40°F to highs of over 90°F.

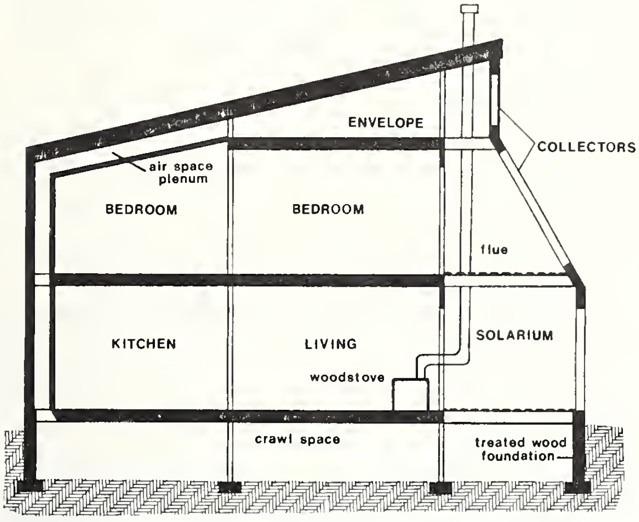
Extensive glazing on the south wall and the roof of the solarium allows the upper levels to become quite warm. A 24-inch-diameter vent fan, installed in the upper west end of the solarium, helps exhaust excess heat in the summer. The upper bedrooms of the home do not seem to overheat, probably due to the insulated wall between those rooms and the solarium.

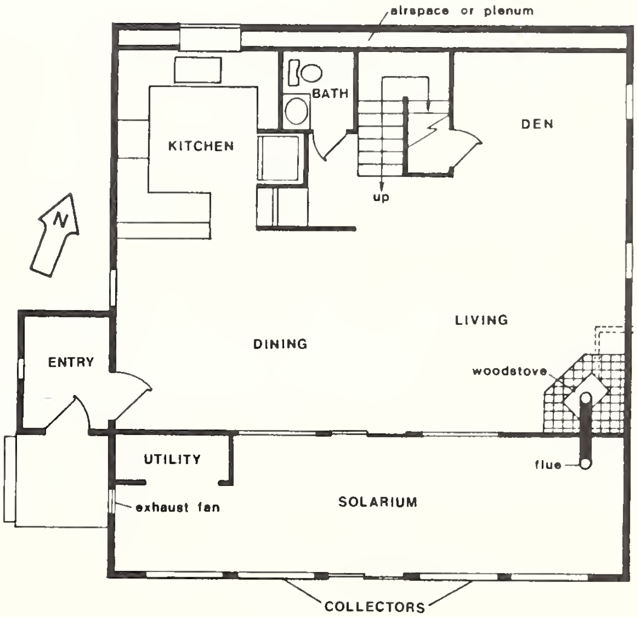
One criticism of the north plenum cavity lies in its potential for fueling a fire; a strong convective updraft of air could add oxygen to a fire near the plenum. Wright solved this problem by placing a temperature-sensitive metal damper in the plenum that will spring shut at a preset temperature.

The home's double-walled construction and good weatherization contribute to its thermal efficiency. Insulating shutters or curtains would enhance efficiency further. In addition, a shelterbelt might reduce infiltration and heat loss caused by the high winds prevalent in the area.

## BUILDING DETAILS

**Design type:** indirect gain
**Total floorspace:** 1,883 sq. ft.
**Heated floorspace:** 1,455 sq. ft.
**Window area** —
South: 376 sq. ft. East: 32 sq. ft.
North: 18 sq. ft. West: 16 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** 12 degrees east of south
**Glazing angle:** vertical
**Thermal storage:** earth
**Auxiliary heating:** wood, electric baseboard
**Insulation** —
Ceiling: fiberglass to R-42
Walls: rigid foam and cellulose to R-27
Floor: none
Foundation: rigid foam to R-19
Windows: none
**Cost of materials and labor:** $51,000
**Cost per square foot:** $27
**Financing:** conventional loan
**Microclimate** —
Degree-days: 8,213
Average summer temperature: 65°F
Average winter temperature: 33°F





Havre

# Richard and Josephine Dontigney

## BUILDING DESCRIPTION

Tucked into a bench overlooking the plains south of Havre, this two-level, earth-sheltered house enjoys a good southern exposure while being protected from cold winter winds. The Dontigneys' three-bedroom home, made from preformed concrete panels, is bermed on all sides but the south, which is glazed to allow direct solar heating of the living room and daylight basement. A vestibule entryway provides access to the garage, kitchen, living room, and basement.

Precast ''Waffle-Crete''® panels form the roof and most of the walls of the house. Because of the excessive weight of the structure, extra-wide foundation footings were poured. The panels were cast with weld plates so they could be drilled and bolted together. The outside of the walls was waterproofed with asphalt emulsion and insulated with 2-inch-thick polystyrene panels.

A 2-by-4-inch studwall on the south contains 3½ inches of fiberglass and is sheathed on the exterior with 2-inch polystyrene panels. The roof panels, supported in part by structural steel I-beams, were welded together. The seams between the panels were sealed with silicone caulk and asphalt emulsion. A thin layer of bentonite then was spread over the entire roof. Two layers of polyethylene sheeting, one 3-mils thick and the other 6-mils thick, waterproof the surface, and 6-inch polystyrene panels insulate the roof. The polystyrene was covered with a final layer of 10-mil polyethylene and 12 inches of earth.

## SOLAR SYSTEM

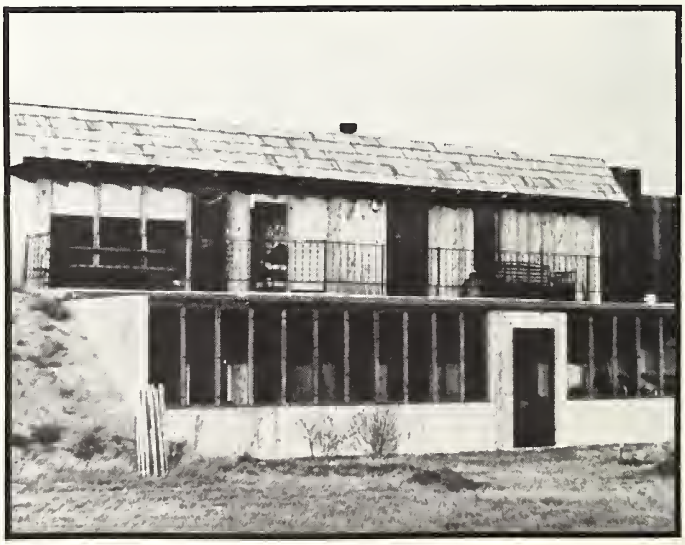
Solar heat is gained directly through 212 square feet of south glazing. A 12-by-44-foot greenhouse on the lower level incorporates used plate glass for glazing. Set in redwood frames, these windows can be removed and replaced with screens to prevent overheating during the summer. The home's concrete floor, walls, and roof provide more than 1,000 cubic feet of thermal storage.

## MAINTENANCE AND LIVABILITY

The large concrete thermal mass, protected by the earth, limits indoor temperature fluctuations. Daytime temperatures in the house, which during the winter range between 62° and 68°F, fall to 60°F in the evening. Backup heating, if needed, is provided by a Vigilant® wood stove. Nighttime heat losses could be reduced by installing thermal curtains or shutters.

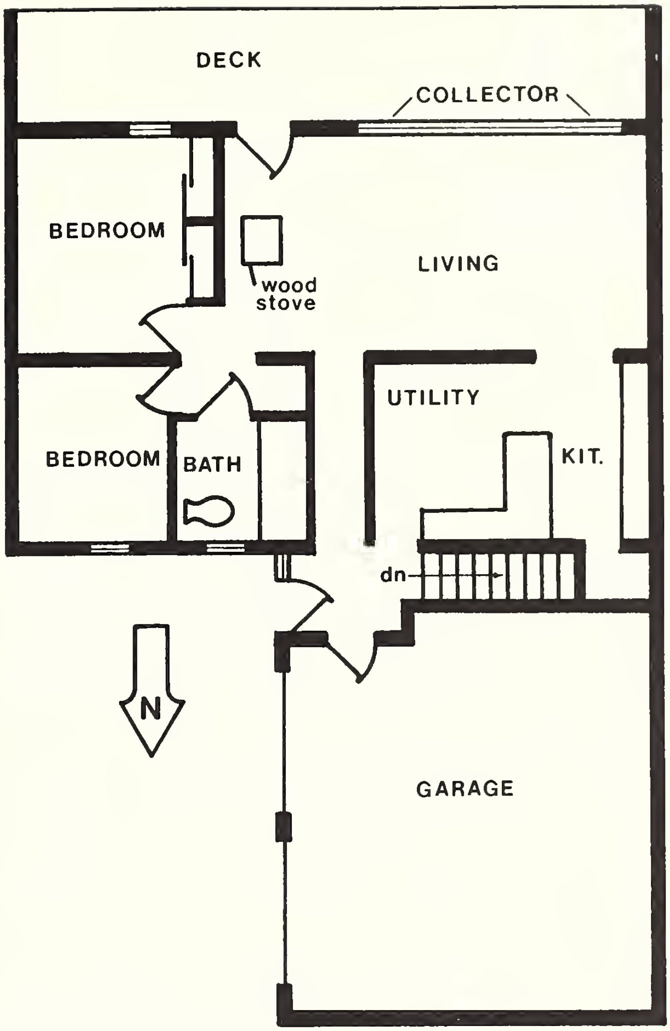
An overheating problem was solved last summer by constructing a 4-foot overhang to shield the south glazing on the upper floor; a concrete balcony shades the windows on the lower floor. Summer temperatures in the home had previously reached 80°F.

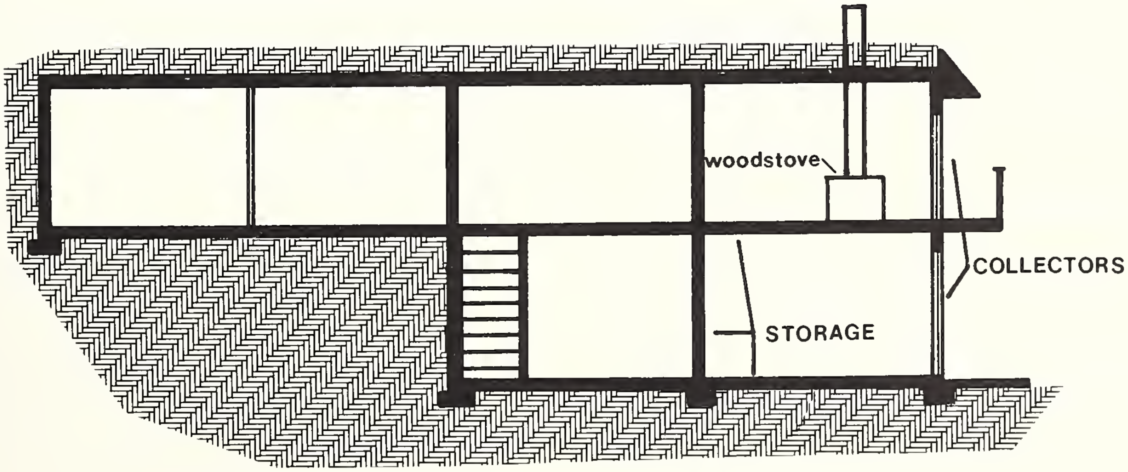
Contrary to the popular belief that underground homes are dark and cold, the Dontigney house is well lighted and evenly heated. The owners have suggested that building costs could have been reduced by consolidating the living space into a single floor.



### BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 3,300 sq. ft.
**Heated floorspace:** 2,700 sq. ft.
**Window area —**
  South: 212 sq. ft. East: 0
  North: 12 sq. ft. West: 0
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** concrete
**Auxiliary heating:** wood, natural gas furnace
**Insulation —**
  Ceiling: beadboard to R-21
  Walls: fiberglass to R-19
  Floor: none
  Foundation: rigid foam to R-7
  Windows: none
**Cost of materials and labor:** $80,000
**Cost per square foot:** $24
**Financing:** conventional loan
**Microclimate —**
  Degree-days: 8,213
  Average summer temperature: 65°F
  Average winter temperature: 33°F





Chinook

# Jerry and Jane McGillivray

## BUILDING DESCRIPTION

The McGillivrays' earth-sheltered, three-bedroom home sits on a gravel hilltop south of Chinook. The lower floor is underground to limit the home's exposure to strong northerly winds. Two second-story bedrooms rise above the grade level and are framed with 2-by-6-inch exterior walls insulated with 6 inches of fiberglass. The above-grade second story has a gable-truss roof covered with asphalt shingles.

The north and west walls of the lower level, which are 8-inch-thick reinforced concrete, rest on oversized footings. The walls are insulated with 4-inch polystyrene panels on the outside. The concrete floor, 6 inches thick, was not insulated. The earth-covered roof rests on a steel I-beam that forms the top of a bearing wall running down the middle of the house. The 2-by-12-inch roof rafters, on 12-inch centers, were covered with ¾-inch treated plywood, a layer of asphalt emulsion, a moisture barrier of 6-mil polyethylene, and 8-inch polystyrene panels. Another layer of 6-mil polyethylene, which seals the entire roof, was covered with 12 inches of soil. The base of the foundation was backfilled with gravel. Additional drainage tiles were not needed because of the good drainage characteristics of the site.

## SOLAR SYSTEM

Solar heat is gained directly through 200 square feet of double-glazed windows. Heat is stored in the concrete floor and walls, and in a 50-cubic-foot cement and stone hearth. Since the concrete walls are well insulated and the concrete mass is in direct contact with the living space, temperature fluctuations are small. Conductive heat losses through the roof and walls are reduced by the insulative earth covering. Earth-sheltering also allows the home to stay cooler in the summer. A 30-inch roof overhang shields the southern glazing from the intense summer sun.

## MAINTENANCE AND LIVABILITY

Heating and cooling of the McGillivray house is aided by the use of vestibule entryways and foam-core steel doors with magnetic weatherstripping. Indoor winter temperatures fluctuate an average of 10°F daily. Without backup heating, the inside temperature drops to a low of around 55°F during the winter. Daytime indoor temperatures average 65°F. During the winter, approximately one cord of wood is burned in a Hurricane wood stove for backup heating; electric baseboard heaters are used only if the house remains unoccupied for several days.

Evening heat losses could have been reduced by installing a frost-break along the south foundation wall to slow the movement of heat from the floor slab to the outside. Insulating shutters and curtains on the south glazing could further reduce heat loss at night.

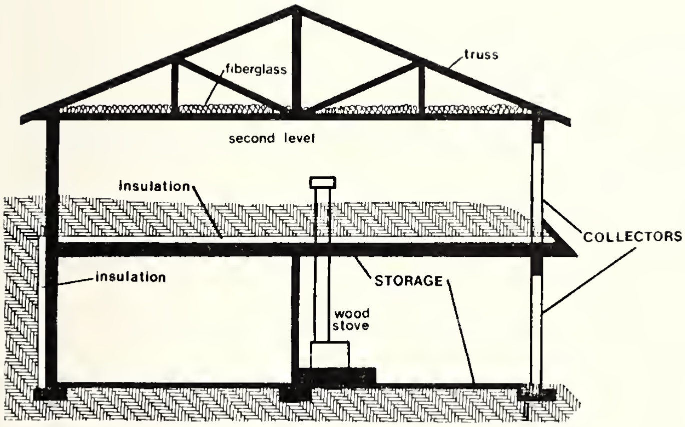
Overheating has not been a problem; a good convective flow of air is created by opening windows on the lower and upper floors. McGillivray said that if he were to build again, he would place the garage on the upper level to increase available living space on the main level. He also would extend the roof overhang on the south to 3 feet and backfill around the perimeter of the foundation with sand, rather than gravel, to avoid puncturing the vapor barrier.

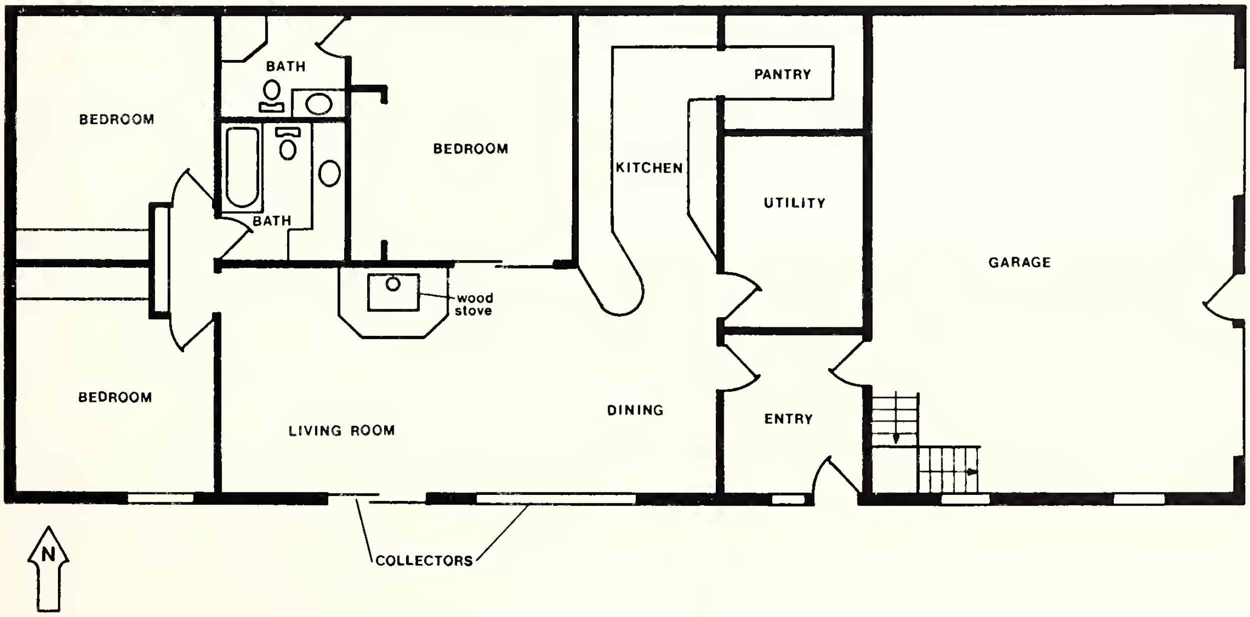
## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 2,560 sq. ft.
**Heated floorspace:** 1,792 sq. ft.
**Window area** —

| | |
|---|---|
| South: 190 sq. ft. | East: 18 sq. ft. |
| North: 0 | West: 12 sq. ft. |

**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** masonry, stone
**Auxiliary heating:** wood, electric baseboard
**Insulation** —
  **Ceiling:** rigid foam to R-38
  **Walls:** rigid foam to R-19
  **Floor:** none
  **Foundation:** rigid foam to R-14
  **Windows:** none
**Cost of materials and labor:** $80,000
**Cost per square foot:** $30
**Financing:** owner
**Microclimate** —
  Degree-days: 8,595
  Average summer temperature: 65°F
  Average winter temperature: 33°F





# ZONE IV

## Southeastern Montana

# The Land And Its Climate

For a distance of 400 miles, the rolling plains of southeastern Montana are broken only by buttes, low hills, tree-lined rivers and creeks, and a few scattered mountain ranges—the Beartooth Mountains to the southwest, and the Rosebud, Pryor, Wolf, and Bighorn mountains to the south. The Bighorn, Rosebud, Tongue, and Powder rivers flow out of these southern mountain ranges to join the Yellowstone River. This is a land of extremes, both in topography and climate.

The climate in southeastern Montana, termed "continental," is typified by an abundance of sunshine, light rainfall, moderate winds, and large seasonal and daily temperature changes. The average annual temperature here, 44°F, is the highest in the state, although this average does not preclude the occurrence of subzero temperatures throughout the area during the winter. Miles City has recorded temperatures of 0°F as early as October and as late as April. The all-time low temperature for this area is -65°F, which was recorded at Ft. Keogh, just southwest of Miles City. Cold waves are generally not prolonged, being broken occasionally by warm, pleasant weather ushered in by chinook winds. Such warming trends, however, can be ended abruptly by blizzards and plummeting temperatures.

Summer in southeastern Montana is characterized by long days of sunshine and occasional hot, dry winds. Daytime temperatures average 80° to 90°F; all the temperature recording stations in this region, with the exception of Red Lodge, sitting at 5,250 feet above sea level, have reported temperatures above 100°F. Daytime temperatures exceed 90°F on the average of 40 to 50 days per year in the eastern part of this zone.

Continental climatic extremes also are evident in annual precipitation records. Average annual precipitation is 14 inches; 73 percent of this amount falls as rain during the April-to-September growing season. June is usually the wettest month of the year, February the driest. Red Lodge holds the record for the highest amount of annual precipitation—35 inches, while Custer Station had the driest year on record—only 1.78 inches. Drought has been a periodic problem in this zone. Average snowfall varies from a low of 13 inches on the prairie to over 100 inches in the mountains.

The prevailing winds on the southern plains are northwesterly during the winter and south-southwesterly during the remainder of the year. Extended periods of sunshine are common in this area even during the winter. During the heating season—October through May—the area receives an average of 55 to 57 percent of the possible sunshine, which makes this region the sunniest in the state.

**CLIMATE SUMMARY**

A) 50-60% possible sunshine* during heating season; low cloud cover

B) Insolation on vertical south wall during average heating season:
Billings — 923 Btu/$ft^2$/day
Lewistown — 821 Btu/$ft^2$/day

C) 7,930 annual degree-days averaged over all stations in zone

D) Wind — from the southwest most of the year, with occasional weather systems approaching from the north in winter; moderate to strong winds year round, tempered by warmer temperatures

E) Temperatures:
Average January temp. (F°) for zone: 19.6
Average August temp. (F°) for zone: 67.9

* The actual hours of sunshine divided by the possible hours of sunshine, expressed as a percentage.

Sources: *WSUN #8 Montana Solar and Weather Information, Montana Solar Data Manual, Montana Renewable Energy Handbook.*

# Design Criteria For Zone IV

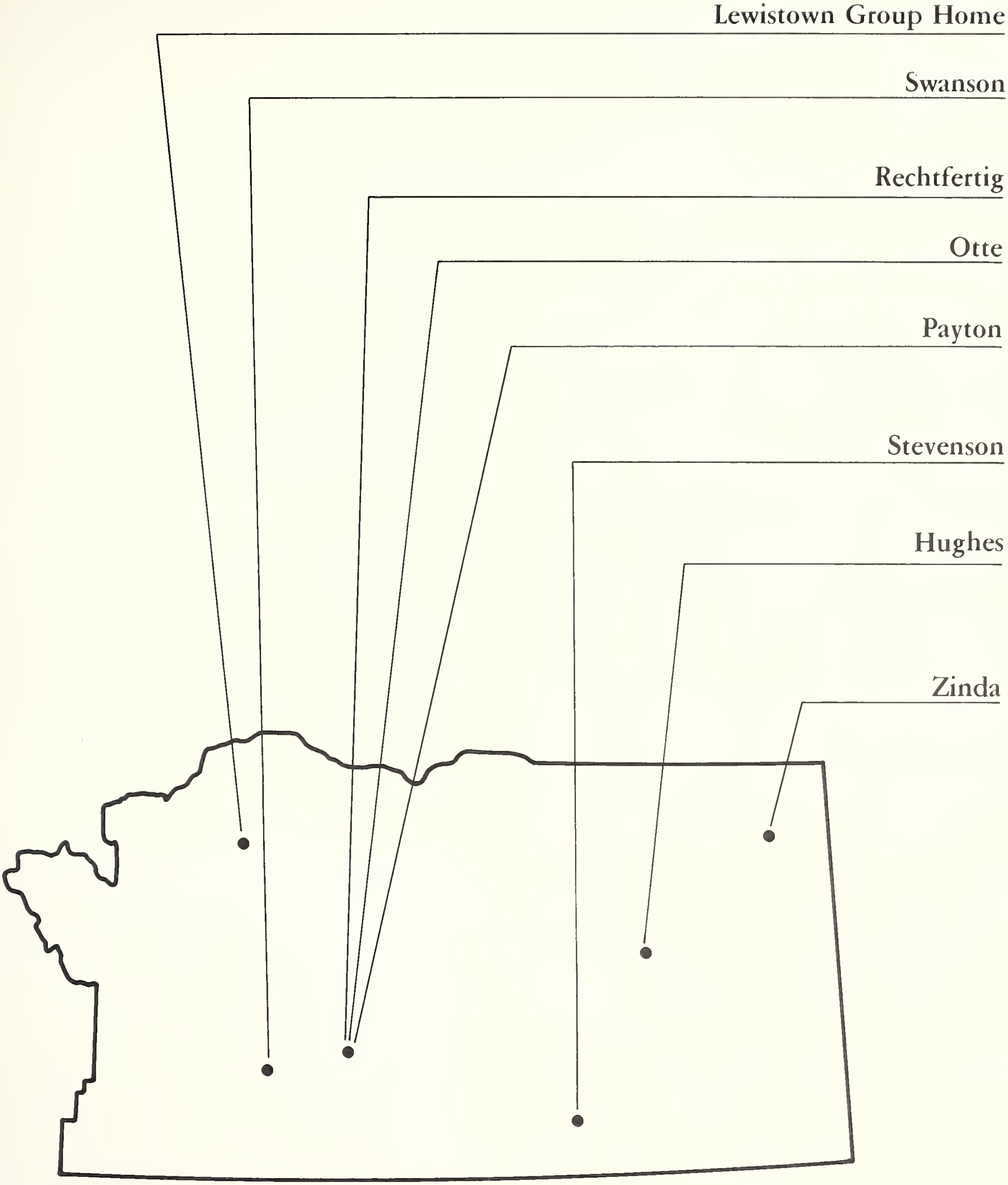
The flat, rolling topography of the southern plains makes the wind a dominant design factor. Another important climatic factor in this area is the high amount of solar radiation available during the heating season.

## ELEMENTS OF DESIGN

The problems associated with wind can be overcome by using landscaping and earth-sheltering techniques. Insulating the exterior of the foundation enables the builder to use the concrete mass of the foundation for heat storage. Additional thermal mass within the living space helps to reduce temperature fluctuations and to absorb excess heat during the spring and fall when roof overhangs don't block incoming sunlight. Trees can be used to shade south and west windows during the summer and to protect the building from prevailing winter winds. To prevent overheating in the summer, builders should not install large windows on the east and west sides of a home. However, small windows or vents are necessary to catch prevailing summer breezes.

## GLAZING

The high amounts of solar radiation available during the heating season make the glazing surface a design priority in this zone. According to Balcomb's *Passive Solar Design Handbook*, discussed in Zone I, a south window area that represents 16 to 32 percent of the total floor area of a home in Billings can be expected to reduce the annual heating requirements of that home by 24 to 31 percent, or by 53 to 76 percent with R-9 nighttime window insulation. In Miles City, a solar collector area that represents 23 to 47 percent of a home's total floor area can be expected to reduce the annual heating needs of that home by 21 to 23 percent, or by 60 to 80 percent if R-9 nighttime window insulation is used. Again, nighttime insulation is a significant factor in determining the amount of energy that can be saved.


Lewistown Group Home
Swanson
Rechtfertig
Otte
Payton
Stevenson
Hughes
Zinda

# Lewistown Group Home

## BUILDING DESCRIPTION

Located in a residential neighborhood in Lewistown, the group home for the Lewistown Association for Retarded Citizens is a large, two-story, wood-frame house with an attached pit greenhouse. Although the orientation of the house is 30 degrees east of south and, thus, is not sited as well as it could be for solar exposure, the home's attached greenhouse receives adequate sunlight during the winter.

The 50-year-old building has been well insulated; 10 inches of cellulose were placed in the attic and 3½ inches were blown into the walls. The single-pane windows and doors were caulked and weatherstripped to help reduce air infiltration. Storm windows provide a second layer of glazing.

Retrofitting the group home began by excavating 5 feet of earth along the south wall of the house and pouring a continuous, reinforced concrete footing. A 4-foot, cinder block foundation wall was built on top of the footing; the block cavities were filled with rebar and cement. After waterproofing this wall with asphalt emulsion, the exterior was insulated with 2 inches of rigid foam, covered with metal flashing above grade, and backfilled.

The greenhouse walls were framed with 2-by-6-inch studs, insulated with 6 inches of fiberglass, and lined with 4-mil polyethylene. The exterior walls were sheathed with ½-inch plywood and sided with wood.

The greenhouse roof is supported by 2-by-6-inch rafters set at a 45-degree angle from the house. The unglazed roof is insulated with 6 inches of fiberglass. Four insulated vents are located at the top of the roof, with four window vents on the lower knee wall of the greenhouse.

## SOLAR SYSTEM

The 420-square-foot pit greenhouse collects sunlight through 483 square feet of double-layered Filon® glazing. Heat is stored in the exposed stone and masonry foundation of the house and the insulated block walls of the greenhouse. To increase the structure's heat-storage capacity, 20 water-filled, 55-gallon steel barrels, painted black, were stacked in the greenhouse.

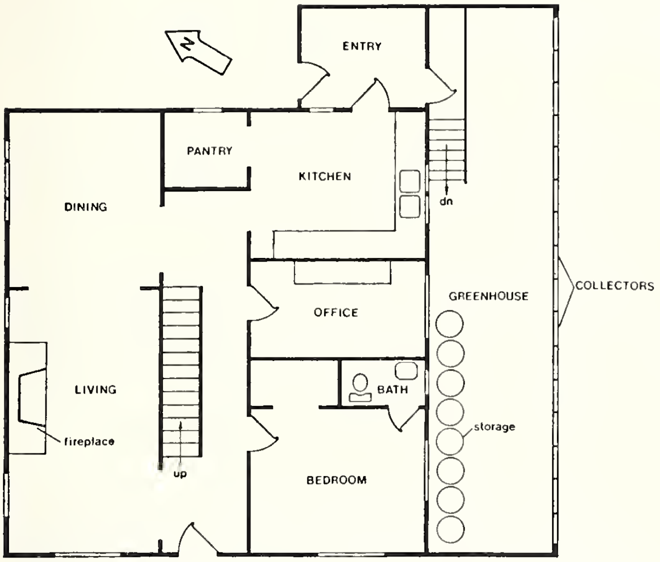
Heated air moves convectively through two doors and five double-hung windows between the greenhouse and the house. Basement windows along the south foundation wall of the house, as well as vents in the greenhouse roof, can be opened to cool the greenhouse convectively.

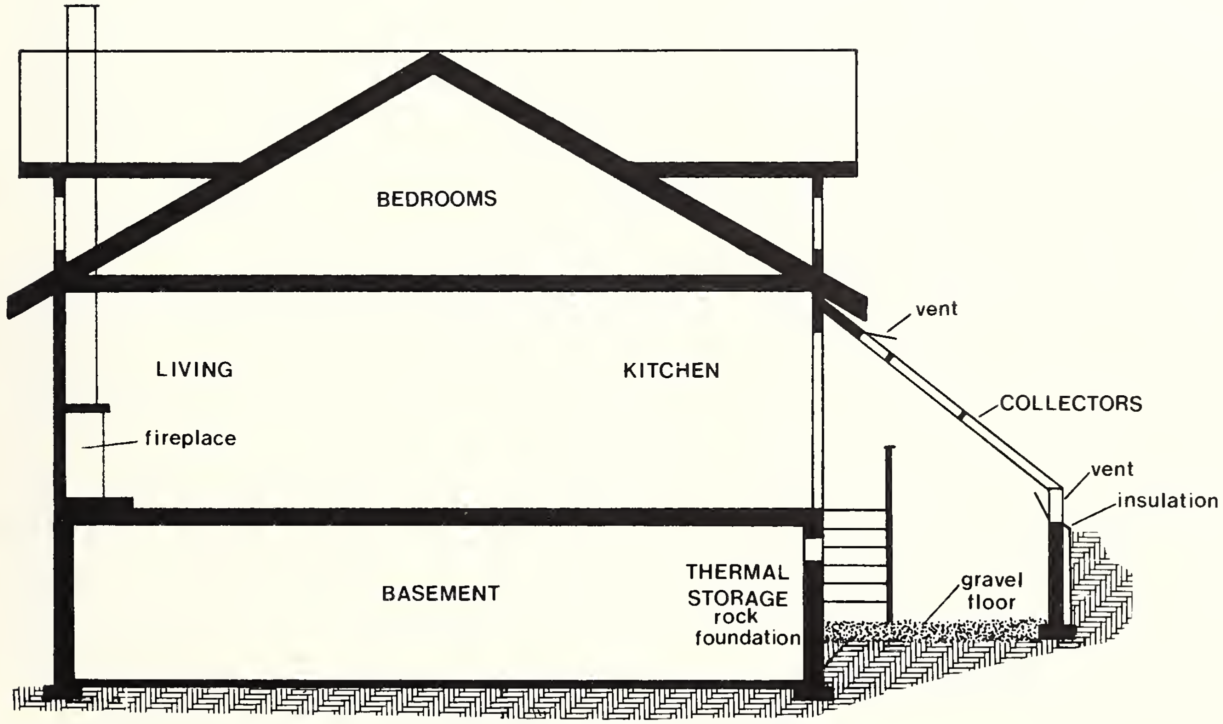
## MAINTENANCE AND LIVABILITY

According to the home's program director, temperatures in the greenhouse range from a low of 55°F to a high of 80°F during March. When needed, a King wood furnace provides auxiliary heat to the house. A gas furnace is thermostatically controlled to supplement wood and solar heating when the inside temperature dips below 65°F.

## BUILDING DETAILS

**Design type:** greenhouse
**Total floorspace:** 2,160 sq. ft.
**Heated floorspace:** 2,160 sq. ft.
**Window area** —
  South: 533 sq. ft.  East: 28 sq. ft.
  North: 46 sq. ft.  West: 65 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** 30 degrees east of south
**Glazing angle:** 45 degrees
**Thermal storage:** masonry
**Auxiliary heating:** wood, gas-fired boiler
**Insulation** —
  Ceiling: cellulose to R-38
  Walls: cellulose to R-12
  Floor: none
  Foundation: rigid foam to R-11 (greenhouse)
  Windows: none
**Cost of materials and labor:** $12,000
**Cost per square foot:** $28
**Financing:** Human Resources Development Council grant, donations
**Microclimate** —
  Degree-days: 8,386
  Average summer temperature: 61°F
  Average winter temperature: 33°F





# C.H. Swanson

## BUILDING DESCRIPTION

This underground, passive solar home is built into a gentle hillside overlooking the Yellowstone River near Columbus. The kitchen, dining room, and living room of this two-bedroom house are located on the south side in order to take full advantage of the light and heat collected through an attached greenhouse and extensive south glazing. An attached garage on the east end of the house is connected to the living space by a vestibule mud room.

The walls of this underground house consist of 8-by-12-foot prestressed concrete panels set vertically on 12-by-30-inch concrete footings. Steel tabs were cast in the panels; the panels then were joined by welding the tabs together. The joints between the panels were sealed with Thoroughseal® , an elastic polymer; the outside joints were covered with a fabric screen. A bentonite paste then was troweled over the panels. One inch of rigid foam insulates the exterior surface of these walls.

The flat roof was constructed from 1-foot-thick prestressed panels 8 feet wide and 28 feet long. Interior prestressed concrete walls serve as both inner partition walls and bearing walls for the roof panels.

Roof seams were waterproofed differently than the walls. First, cement was poured into the joint, then a nonshrinking grout was applied. Finally, a thin layer of asphalt cement was used to fill the seam. Adequate roof drainage was ensured by spreading a 10-inch-thick layer of bentonite on the south, tapering to 6 inches on the north. Four inches of rigid foam was laid over the bentonite and sealed with a layer of 6-mil polyethylene and 18 to 24 inches of soil.

The south-facing, 2-by-4-inch studwall is nonbearing and is insulated with 3½ inches of fiberglass. No vapor barrier was installed in this wall; however, the outside of the wall was covered with 1 inch of rigid foam before it was surfaced with dark, native stone.

## SOLAR SYSTEM

A prefabricated Lord and Burnham greenhouse is attached to the west end of the south wall. Its single-glazed roof and wall sections are fastened to aluminum framing members. The collected heat enters the house through a large double-glazed sliding glass door. Heated air is distributed with a small fan that pulls warm air from the top of the greenhouse into a duct system under the concrete floor of the house. Cold air return ducts on the north and south edges of the floor allow cooler air to return to the greenhouse for warming. Outside combustion air, which enters the system through soffits in the south overhang, is preheated in the greenhouse before it is distributed throughout the house.

Direct solar gain occurs through 220 square feet of double-glazed windows. This heat is stored in a 900-square-foot, 4-inch-thick concrete slab floor surfaced with dark quarry tile. Additional storage is provided by a 12-foot-long interior concrete bearing wall covered with dark stone. The insulated concrete floor, walls, and roof all contribute to the thermal-storage capacity of the Swanson house.

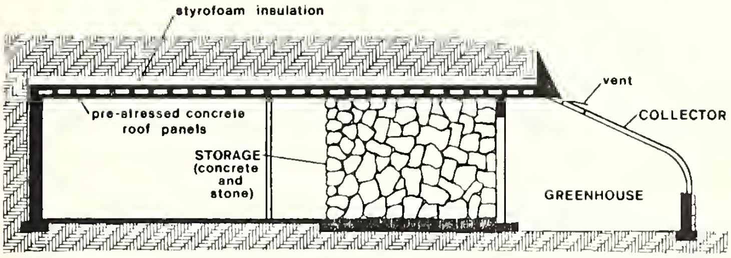
Exterior thermal shutters, manually operated from the inside, are mounted in an aluminum valance above the south windows. Lowered in the evening on aluminum tracks, the shutters consist of horizontally hinged aluminum slats filled with hollow plastic baffles 5/8 of an inch thick. These shutters, manufactured by the Pease Company, add an estimated R-value of 3.5 to the south windows.

Several architectural features aid summer cooling. A 4½-foot mansard roof overhang shades the south wall. Also, electrically operated roof vents in the greenhouse as well as casement windows on the south provide ventilation, while the surrounding earth helps to temper summer heat.

## MAINTENANCE AND LIVABILITY

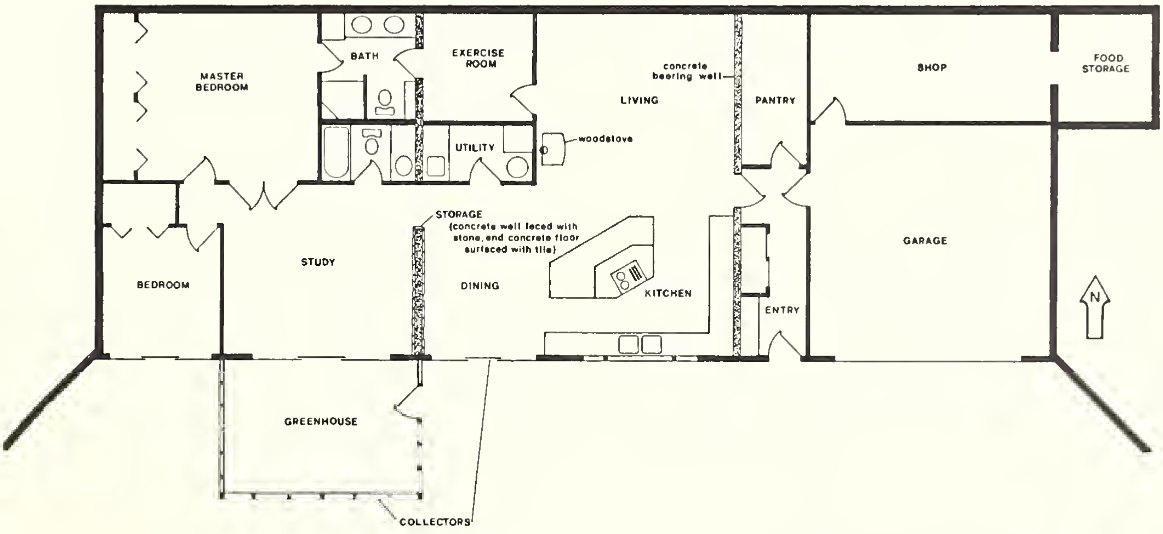
Conservation is crucial to the effectiveness of this passive solar system. Steel thermal doors with magnetic weatherstripping, adequate insulation materials, a well-designed open floorplan, and careful construction are integral to effective performance.

The Swanson house has not been monitored extensively for solar-heating performance. However, current information indicates that indoor winter temperatures range between 68° and 75°F. Backup heating is provided by a Vigilant® wood stove. To date, a supplemental electrical heating system has not been used. Swanson suggests that thermal curtains and double-glazing would help to reduce temperature fluctuations in the greenhouse.


styrofoam insulation
pre-stressed concrete roof panels
STORAGE (concrete and stone)
vent
COLLECTOR
GREENHOUSE

### BUILDING DETAILS

**Design type:** direct/isolated gain
**Total floorspace:** 1,800 sq. ft.
**Heated floorspace:** 1,800 sq. ft.
**Window area** —
  South: 220 sq. ft. East: 0
  North: 0 West: 0
**Glazing:** two layers of glass
**Glazing orientation:** 3 degrees west of south
**Glazing angle:** vertical
**Thermal storage:** concrete, stone
**Auxiliary heating:** wood, electric baseboard
**Insulation** —
  Ceiling: rigid foam to R-22
  Walls: fiberglass and rigid foam to R-27
  Floor: none
  Foundation: rigid foam to R-5.5
  Windows: plastic-baffle shades
**Cost of materials and labor:** $85,000
**Cost per square foot:** $47
**Financing:** owner
**Microclimate** —
  Degree-days: 6,909
  Average summer temperature: 66°F
  Average winter temperature: 35°F



**Billings**

# Peter Rechtfertig

Peter Rechtfertig was awarded a $1,265 grant from the Renewable Energy Program in January 1978 to demonstrate that a significant amount of usable solar heat could be gained in a home merely by installing a series of south-facing windows with insulated shutters. No special materials or construction methods were to be used with this design, which is suitable for a new house or for a properly sited retrofit. To make arrangements to visit the house, contact Rechtfertig at 1030 Harvard Ave., Billings, MT 59102; telephone 252-7421.

## BUILDING DESCRIPTION

Rechtfertig incorporated passive solar features into a second-story dormer addition to his 1,110-square-foot, one-story home. This addition created an additional 480 square feet of living space. The house's south-facing roof was raised to make room for a vertical row of collection windows with a surface area of 125 square feet.

Rechtfertig calculated that if the house were insulated to reduce its overall heat loss, a large percentage of the solar heat entering the windows would be held long enough to assure a comfortable temperature.

At night, insulated shutters close off the row of windows to slow heat loss. All the south-facing windows can be opened in the summer to keep heat from accumulating upstairs. Large shade trees close to the east and west sides of the house also aid summer cooling.

## SOLAR SYSTEM

An existing attic was extensively modified to create this passive solar addition, which houses two bedrooms, a small nursery, and a bathroom. The roof area over the addition was stripped of shingles, hinged, and raised in 6-foot sections. Rafters were installed for interior support. Siding, shingles, and insulation then were installed.

The south collection windows of the dormer are all single glazed. Aluminum combination storm windows are added in the winter. The insulating shutters for these windows were fabricated by sandwiching 1-inch polystyrene between layers of ½-inch unfinished fiberboard. Each shutter was covered with fabric to provide an attractive interior surface. The shutters were hinged at the top of each window to allow them to be opened and closed by hand. The area between the windowsill and the shutter was sealed with weatherstripping.

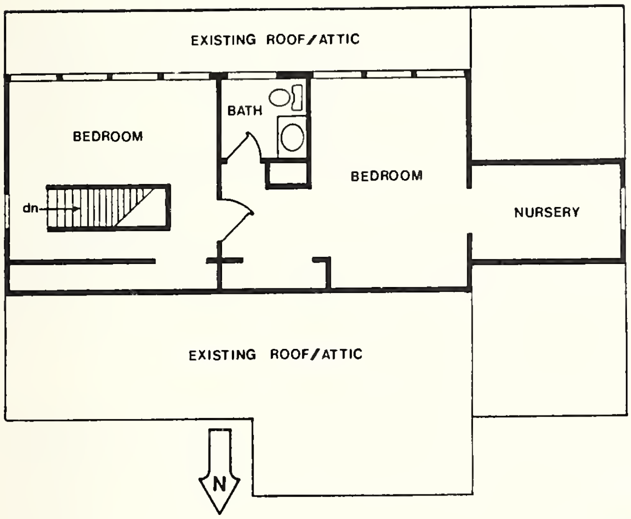
## MAINTENANCE AND LIVABILITY

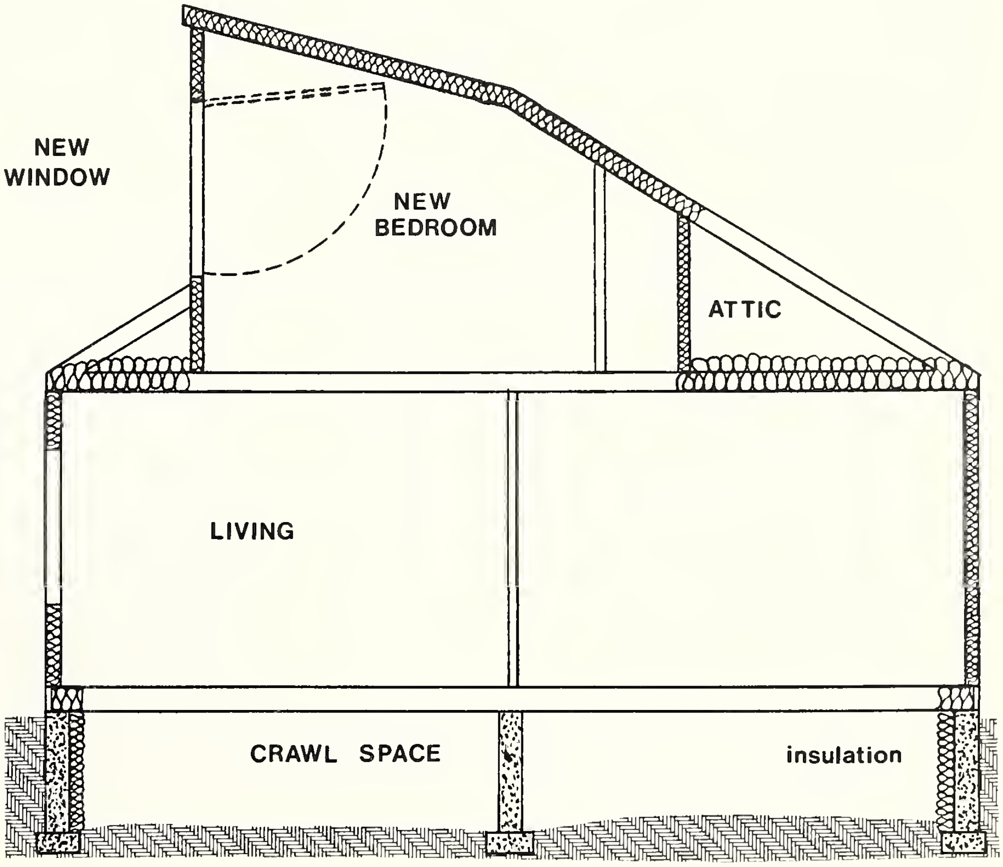
Rechtfertig has discovered a few problems that affect the performance of this system. The most critical problem involves frost on the window. When nighttime temperatures dropped near or below 0 °F, moisture in the airspace between the storm window and the inner glazing condensed and froze. Thus, heat gain for much of the following day was reduced until the frost thawed and evaporated. Rechtfertig believes that double-glazed windows without outer storm windows would have been a better choice. Also, he noticed that the inconvenience of opening and closing the shutters often caused them to be ignored, thereby undermining the effectiveness of the system.

Rechtfertig is convinced that the performance of his passively heated addition has met or exceeded his expectations. By monitoring natural gas consumption in the home before the project began and again after the project was completed, Rechtfertig found that in 1976 17.1 cubic feet of gas were required per degree-day, as compared to 16.1 cubic feet per degree-day in 1978. The lowered consumption could be attributed to added insulation as well as to solar gain. Nevertheless, despite adding 480 square feet to the home's total floor space, the house was heated at a lower cost in 1978 than in 1976. In fact, one-third less gas was used per square foot after the passive solar features were installed.

## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 1,590 sq. ft.
**Heated floorspace:** 1,590 sq. ft.
**Window area (retrofit)** —
  South: 125 sq. ft. East: 4 sq. ft.
  North: 0 West: 4 sq. ft.
**Glazing:** one layer of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** none
**Auxiliary heating:** natural gas furnace
**Insulation** —
  Ceiling: R-19
  Walls: R-13
  Floor: none
  Foundation: R-12
  Windows: foam-core panels
**Cost of materials and labor:** $3,472 (retrofit)
**Cost per square foot:** $7 (retrofit)
**Financing:** owner, Renewable Energy Program grant ($1,265)
**Microclimate** —
  Degree-days: 7,265
  Average summer temperature: 66°F
  Average winter temperature: 35°F





Ballantine

# Leslie and Peggy Otte

## BUILDING DESCRIPTION

The three-bedroom Otte home is set in a field overlooking open prairie. Sheltered by pines and some deciduous trees, the house exhibits clean, contemporary lines, accented by opposing-shed roofs and a clerestory. An attached carport extends the north roof line.

The home's foundation consists of an 8-inch-thick concrete foundation wall covered on the outside with 2 inches of rigid foam. The inside of the foundation is backfilled with pit-run gravel and covered by a 4-inch concrete slab. The slab is finished with dark red ceramic tiles.

This direct gain, two-story home was built with conventional 2-by-4-inch studwalls insulated with 3½ inches of fiberglass. One inch of foil-faced Thermax® sheaths the exterior. A 6-mil polyethylene film was used as a vapor barrier on all the exterior walls and on the ceiling. The truss roof is insulated on the horizontal chord with 12 inches of fiberglass.

## SOLAR SYSTEM

The home's direct gain heating system employs 160 square feet of double-glazing on the south and 158 cubic feet of thermal mass in the ceramic-tiled concrete floor. Concrete walls provide additional thermal mass, as does a 520-cubic-foot, sand-filled cinder block chimney that separates the south-facing living room from the den. This chimney, which is faced with native stone, and serves as the flue for a Defiant® wood stove, also provides a storage mass for wood heat. A 36-inch ceiling fan in the living room recirculates warmer air that stratifies in the upper levels of the house.

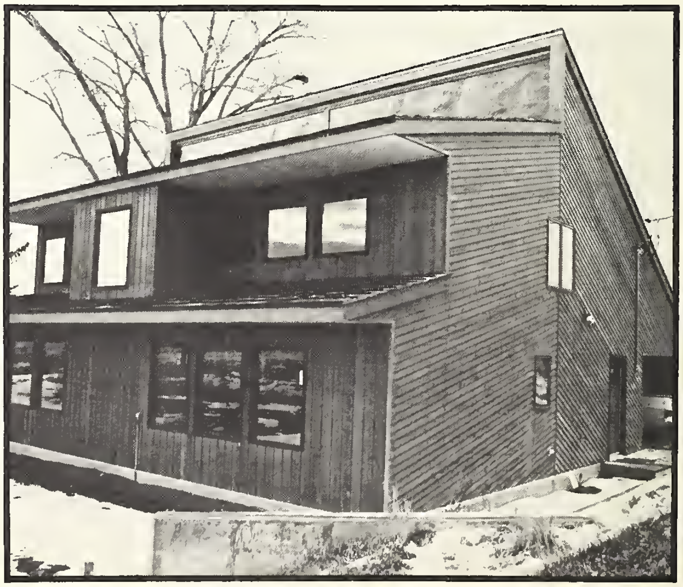
The home's opposing-shed roof contains a clerestory window wall, glazed with Kalwall fiberglass, that may be redesigned to accommodate a solar water heater in the future. The windows are shaded from direct summer sunlight by a 4-foot overhang on the top floor and a 3-foot overhang on the lower level.

## MAINTENANCE AND LIVABILITY

The home's open floor plan allows heated air to move convectively throughout the structure. A vestibule entry on the north and a mud room entrance on the east buffer the living area from outside temperatures. Foam-core steel doors with magnetic weatherstripping help to reduce conductive heat loss and air infiltration.

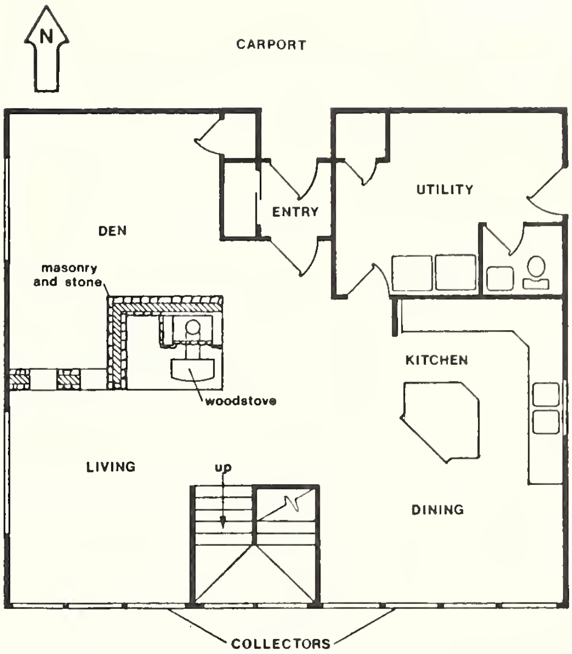
Interior temperatures vary from a low of 60°F in the winter to a high of 70°F during the summer. Through two heating seasons the Ottes have burned only two cords of wood for supplemental heat. An electric backup heater has never been used.

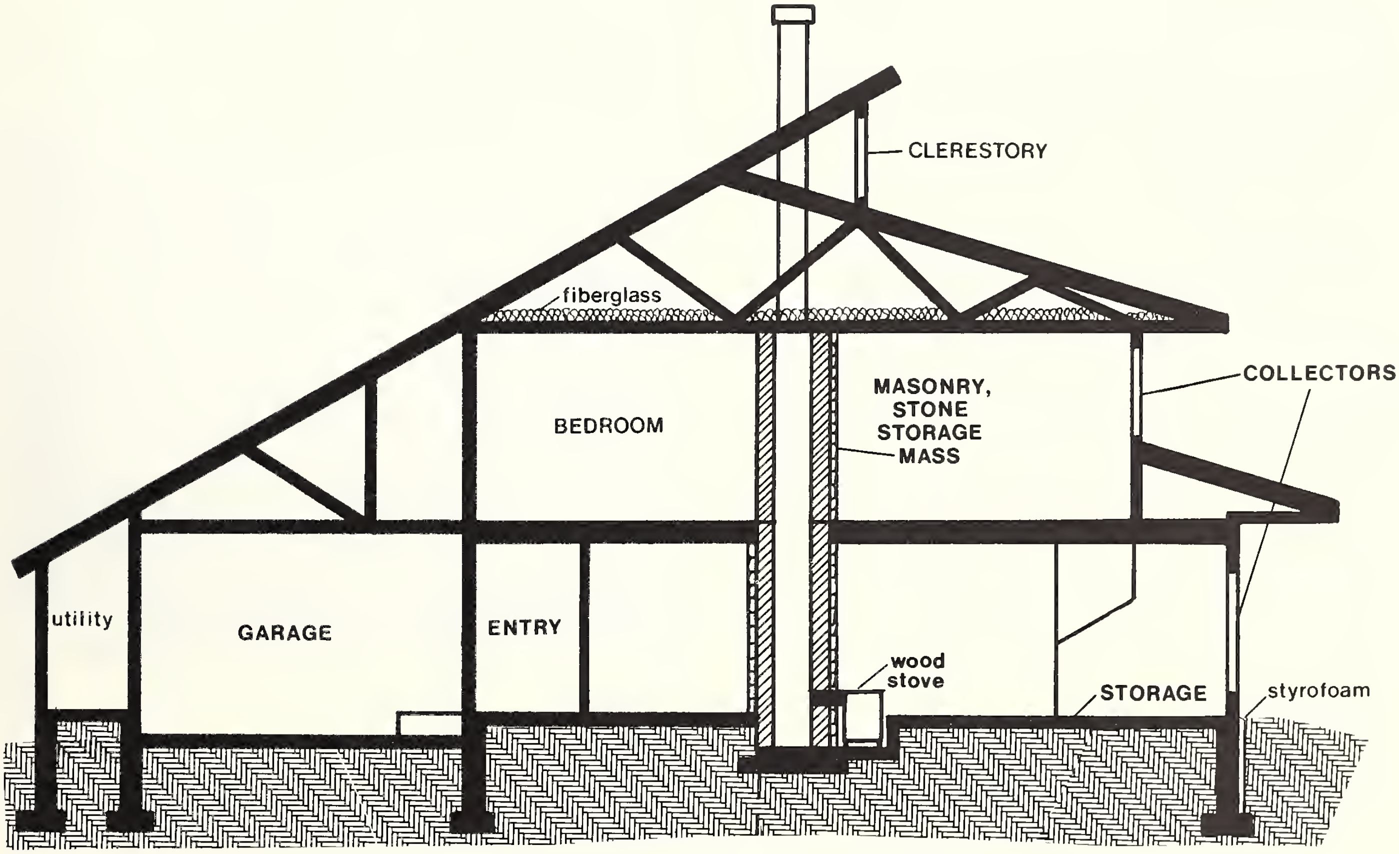
The Ottes are very pleased with the performance of their direct gain home. Nevertheless, they recommend using 2-by-6-inch exterior studwalls so that more insulation can be placed in the walls, and adding insulating curtains to reduce evening heat loss. They also recommend using triple-glazed windows on the east and west walls and installing an outside air intake for wood stove combustion.



## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 1,800 sq. ft.
**Heated floorspace:** 1,800 sq. ft.
**Window area** —
  South: 160 sq. ft.  East: 24 sq. ft.
  North: 0  West: 36 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** concrete, masonry, stone
**Auxiliary heating:** wood, electric baseboard
**Insulation** —
  Ceiling: fiberglass to R-38
  Walls: fiberglass and rigid foam to R-21
  Floor: none
  Foundation: rigid foam to R-11
  Windows: none
**Cost of materials and labor:** $56,000
**Cost per square foot:** $31
**Financing:** Federal Land Bank
**Microclimate** —
  Degree-days: 6,909
  Average summer temperature: 66°F
  Average winter temperature: 35°F





# Jerry Payton

## BUILDING DESCRIPTION

This two-story, earth-sheltered home is set into a south-facing hill overlooking the rolling prairie east of Billings. Payton's three-bedroom house uses the surrounding environment to temper the climatic extremes common in southeastern Montana.

The exterior of the concrete foundation is waterproofed and insulated with 2 inches of polystyrene. The exposed southern foundation wall is faced with dark stone. Buried perforated tile provides drainage around the foundation.

The 2-by-6-inch exterior walls for the above-grade second level are insulated with 6 inches of fiberglass. A standard shed roof is supported by 2-by-12-inch rafters set on a steel I-beam at midspan. The roof is sheathed with ¾-inch treated plywood, sealed with 1/8-inch butyl sheathing, and insulated with 2 inches of polystyrene. The roof was covered first with 2 inches of sand and then with 10 inches of native soil.

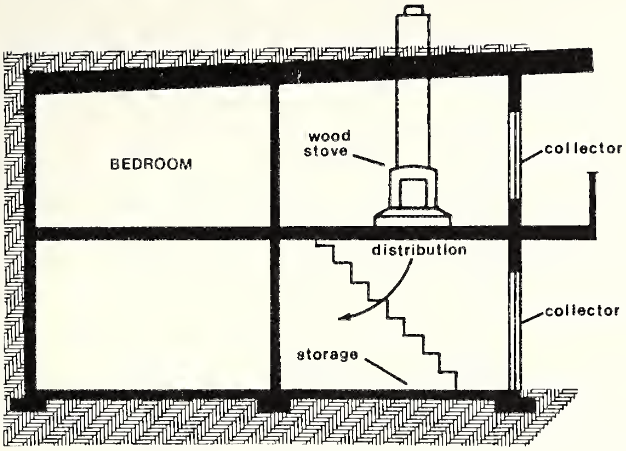
## SOLAR SYSTEM

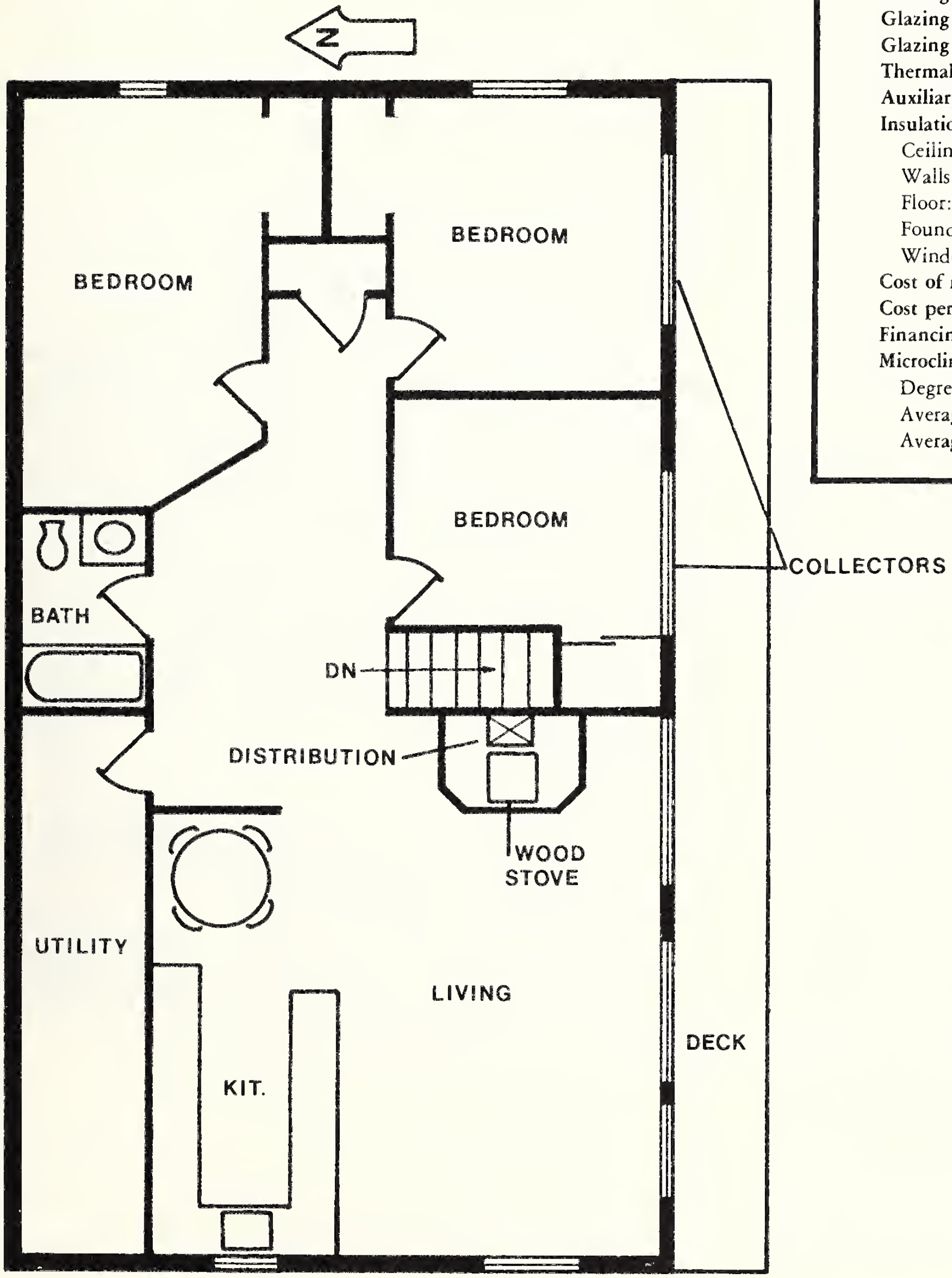
Solar heat is gained directly through 231 square feet of wood-framed, double-glazed windows that open to the living and recreation rooms. The 4-inch-thick concrete floor, concrete walls, and masonry-block and stone hearth provide thermal storage. A 4-foot roof overhang and a second-floor balcony on the south shade the windows on each level from the high summer sun. Casement windows on the east and west open for summer ventilation.

## MAINTENANCE AND LIVABILITY

The home's open floorplan encourages air and heat to circulate throughout the structure. However, because a wood stove was placed on the upper level rather than downstairs, the stove cannot effectively heat the lower level. This problem is aggravated by an open stairwell that permits any warm air collected in the lower level to move quickly upstairs. Although a hot air return plenum was installed to circulate the warmer air back down to the first floor, its proximity to the open stairwell allows circulated air to migrate back upstairs before it can warm the lower level. The Paytons believe the problem could have been avoided with a single-story design, or by relocating the warm air vent in the basement, away from the stairwell.

A low winter temperature of 54 °F has been recorded in the Payton's home. Evening temperatures average 65 °F, while on a sunny day the temperature will rise above 70 °F. According to the Paytons, heat loss could be reduced by installing thermal curtains and by constructing the roof with prestressed concrete panels, which would allow more earth to be placed on the roof.





## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 2,800 sq. ft.
**Heated floorspace:** 2,100 sq. ft.
**Window area** —
South: 231 sq. ft. East: 19 sq. ft.
North: 0 West: 24 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** south
**Glazing angle:** vertical
**Thermal storage:** concrete
**Auxiliary heating:** wood, electric baseboard
**Insulation** —
Ceiling: rigid foam to R-35
Walls: fiberglass to R-19
Floor: none
Foundation: rigid foam to R-7
Windows: none
**Cost of materials and labor:** $73,000
**Cost per square foot:** $26
**Financing:** Veterans Administration loan
**Microclimate** —
Degree-days: 6,909
Average summer temperature: 66°F
Average winter temperature: 35°F

Birney

# Mike Stevenson

## BUILDING DESCRIPTION

Birney architect Mike Stevenson remodeled an old sandstone house built in 1910 to create a passively heated office space. As one part of the remodeling process, Stevenson designed and built a solar porch onto the building's south-facing wall. As designed, sunlight passing through the porch glazing would be stored in the building's original 18-inch-thick sandstone walls. The remodeled design includes a vestibule entry on the north that serves as both an unheated storage area and a dead air space to reduce heat loss and air infiltration.

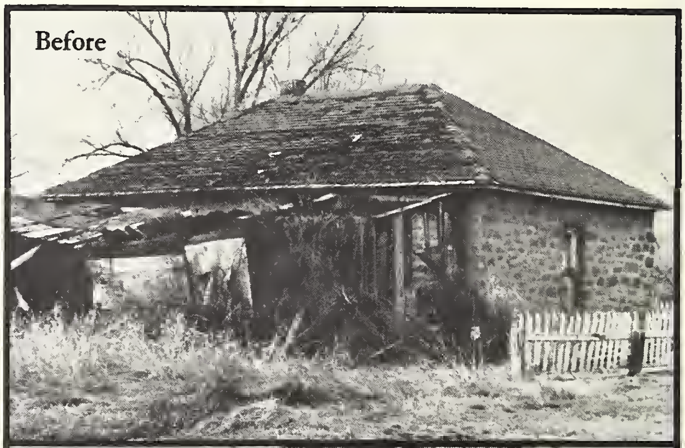
Due to the age and condition of the home's interior, the floor joists had to be replaced; 6 inches of fiberglass were added to the floor during the replacement process. The inside of the sandstone walls was furred out with 2-by-2-inch studs and covered with sheetrock. Interior insulation was not added so that heat stored in the wall could radiate into the office space. After some ceiling joists were replaced, 10 inches of fiberglass insulation were added to the ceiling. To increase natural lighting in the office, three triple-glazed Lexan® skylights were framed into the ceiling.

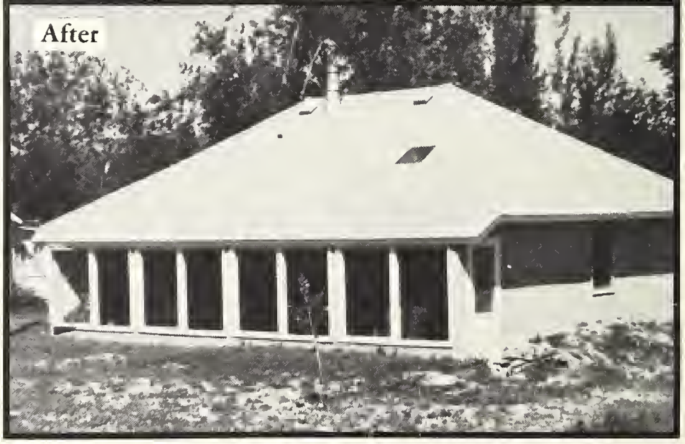
The solar porch, added after the interior was remodeled, features post-and-beam construction. The 2-by-4-inch interior studwall below the windows was insulated with 3 ½ inches of fiberglass, while the bottom 2 feet of the exterior wall were insulated with 1 inch of Thermax® . The remaining exterior sandstone walls were furred out with 2-by-4-inch studs, insulated with 3 ½ inches of fiberglass, and sheathed with 1 inch of Thermax® . A fiberglass-reinforced bonding cement, CuBond® , was used to texture the entire exterior before soil was bermed up against it.

## SOLAR SYSTEM

The sandstone wall behind the porch is painted black to increase its capacity to absorb winter sunlight entering through 160 square feet of double-glazed windows. New double-hung windows set in the sandstone wall can be opened to allow heated air to enter the office convectively. Stored heat also passes conductively through the stone wall into the office area.

Large cottonwood trees and a roof overhang shade the solar porch during the summer. Windows in the office and the solar porch can be opened at night to increase ventilation and cooling.





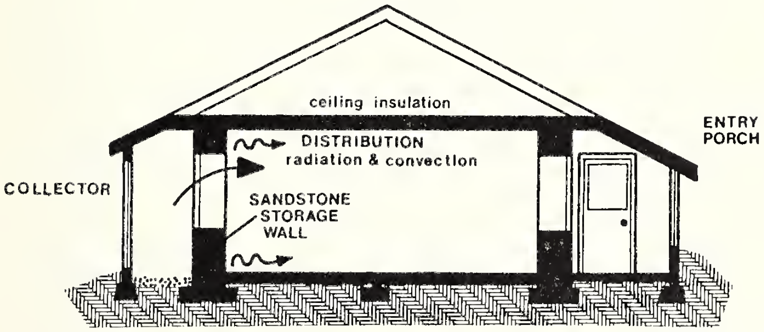
## MAINTENANCE AND LIVABILITY

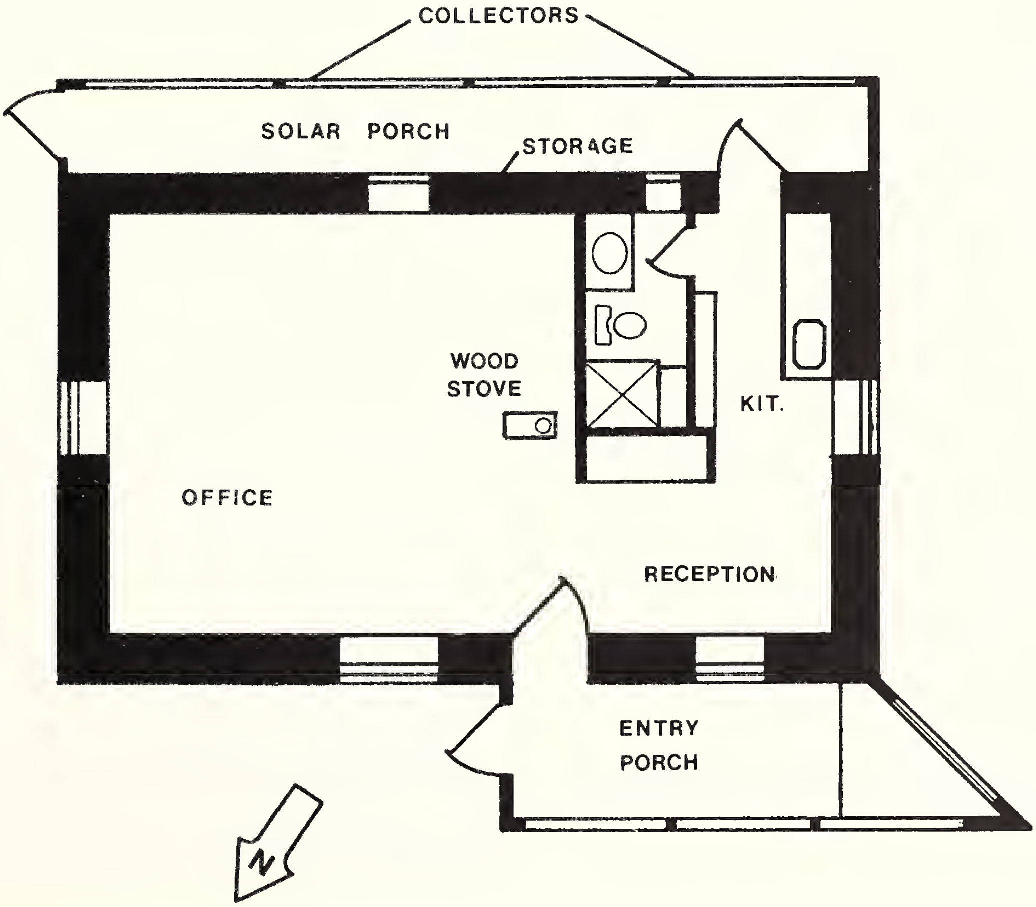
Due to the orientation of the original building, 30 degrees from true south, the solar porch provides only supplemental heat to the office. Winter temperatures range from a low of 40°F in the evening to 75°F on a sunny day.

A Jotul wood stove and an electric wall heater provide additional heat for the office. A ceiling fan prevents air stratification. Due to the supplemental solar heat and increased insulation, Stevenson had to burn only 1½ cords of wood during the 1980-1981 heating season. Stevenson estimates his energy use in this retrofitted building is 4.5 Btu per degree-day per square foot, or about one-half of the energy necessary to heat a conventional building of the same size.

### BUILDING DETAILS

**Design type:** indirect gain
**Total floorspace:** 850 sq. ft.
**Heated floorspace:** 725 sq. ft.
**Window area** —
South: 160 sq. ft. East: 12 sq. ft.
North: 24 sq. ft. West: 12 sq. ft.
**Glazing:** two layers of glass
**Glazing orientation:** 30 degrees east of south
**Glazing angle:** vertical
**Thermal storage:** rock, masonry
**Auxiliary heating:** wood, electric baseboard
**Insulation** —
Ceiling: fiberglass to R-30
Walls: fiberglass to R-19
Floor: fiberglass to R-19
Foundation: none
Windows: none
**Cost of materials and labor:** $17,000
**Cost per square foot:** $20
**Financing:** conventional loan
**Microclimate** —
Degree-days: 8,000
Average summer temperature: 66°F
Average winter temperature: 34°F





Miles City

# Kurt Hughes

Kurt Hughes received a $5,400 grant from DNRC in 1978 to partially finance a passive solar heating system for the two-story home he was planning to build south of Miles City. Hughes hoped to show that an aesthetically pleasing, passive solar home could be built for less than $40,000, and that the home could draw 60 percent of its heat from the sun.

The public is welcome at the site, located 9 miles south of Miles City. For information on the project or to arrange for a visit, contact Hughes at Tongue River Stage Road, Miles City, MT 59301; telephone 232-4488.

## BUILDING DESCRIPTION

This 1,200-square-foot, one-story house was built in a trapezoidal shape, with the long side facing south. Such a design deflects cool northwest winds and incorporates a large southern side for solar collection. The roof slopes from a high peak on the southern side to a low north wall. The house is nestled into a hillside on the north and bermed with earth on the east and west. A juniper hedge and several spruce trees on the north also help to buffer the home from winter winds.

The north, east, and west foundation walls are waterproofed with asphalt emulsion and insulated with 4 inches of rigid foam. The south foundation wall is uninsulated. The 2-by-4-inch studwalls contain 3 ⅓ inches of fiberglass and are sheathed with a textured exterior plywood. The inverted-truss shed roof contains 12 inches of fiberglass insulation.

## SOLAR SYSTEM

Solar heat is gained through three rows of Anderson Windowall® glass windows, which cover about three-fourths of the 17-foot-high south wall. Together these windows provide a total collection area of 410 square feet. Window Quilt® curtains on a large roller insulate the windows at night.

Sunlight passing through the collection windows falls on a curved storage wall and a bare concrete floor. The 4-inch-thick concrete floor rests on a 240-cubic-foot, 12-inch-thick gravel bed. The storage wall contains 109 cubic feet of sand-filled concrete block. The wall was curved to increase the amount of sunlight that could strike a wall of its volume. The floor and wall provide a total net storage area of 694 cubic feet; this combined mass is capable of storing about 250,000 Btu of heat. The home's concrete walls, insulated on the exterior with polystyrene, can store another 257,000 Btu.

As many rooms as possible were placed directly against the storage wall; only one bedroom and a lightly heated storage room do not intersect the wall. A small duct carries heat from the top of the storage wall into the isolated bedroom. The living room, located between the collection window and the storage wall, sits below the floor level of the house. This sunken design allows cool air to be trapped in that portion of the house that receives the most sunlight. A high-efficiency wood-burning stove was installed in the living room for supplemental winter heating.

A split-unit heat pump, with its ductwork distribution system set into the concrete floor along the perimeter of the house, also provides backup space heating. By locating the duct outlets near the walls rather than in them, heat loss through the walls is reduced. Because less heat is lost through the walls, the efficiency of the heat pump is increased.

One cooling feature of the home is a sun shade that can be drawn to cover the collection windows. Constructed from a white nylon knit fabric, the shade can be raised, lowered, or completely removed to control the amount of sunlight entering the building. The shade extends on a cable system from the peak of the roof to the edge of a concrete patio slab along the south side of the house. Because the shade is fabric, air flow through the windows is not impeded.

Several other features promote cooling. The house's semisubmerged design helps to insulate the building from the heat, while its concrete walls and floors reduce temperature fluctuations. Also, a row of small windows in the north wall of the home is shaded by shrubs and pine trees. Cool shaded air can be drawn into the house through these windows and exhausted through the upper row of southern collection windows.

Soffit vents, located under the eaves on the north side of the house, allow cool air to enter the attic; warm air from the attic is exhausted through the roof by a thermostatically controlled power vent. Cooling the attic reduces heat gain through the ceiling.

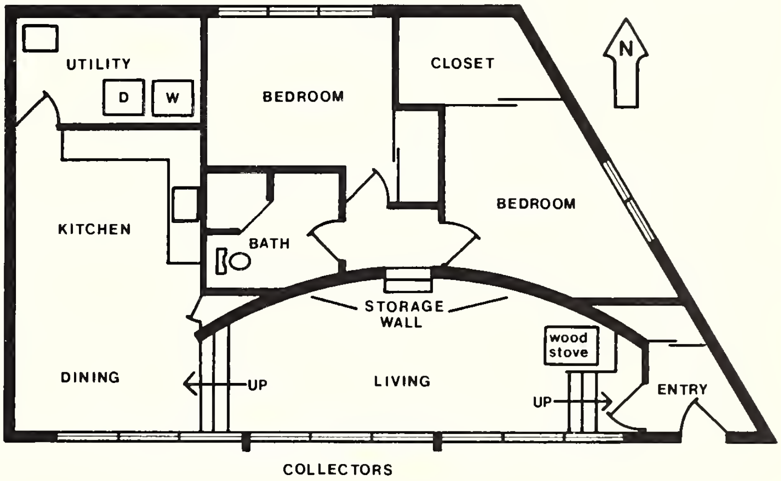
## MAINTENANCE AND LIVABILITY

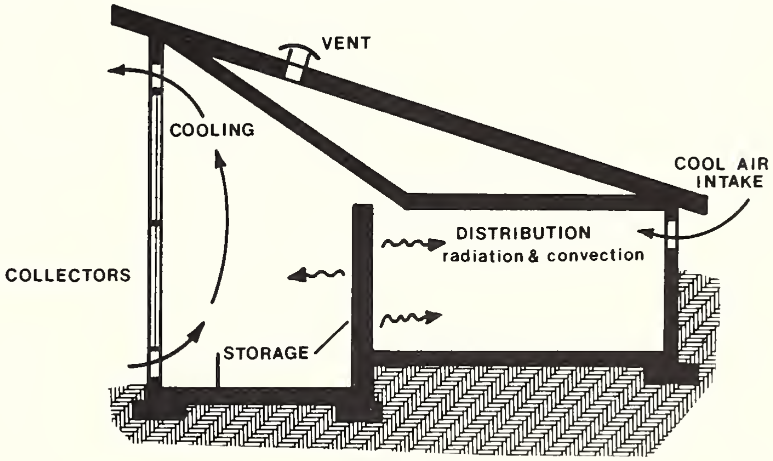
Hughes recommends increasing thermal storage by 25 percent and decreasing southern glazing by the same amount to reduce summer heat gain and winter heat loss. He also would like to increase the insulation in the east and west walls to 6 inches and increase the structural strength of the south wall to prevent window vibration and damage in high winds. The efficiency of the wood stove could be increased by using outside combustion air, while a ceiling fan in the 17-foot-high living room would help to reduce thermal stratification.

Hughes estimated that as much as 85 percent of the home's heat load between mid-February and October of 1979 was supplied by the sun. Preliminary results of independent monitoring conducted through a grant from DNRC's Renewable Energy Program have generally confirmed this estimate. Additional heat, when needed, is supplied by the wood-burning stove in the living room. The heat pump is rarely used.

### BUILDING DETAILS

**Design type:** direct/indirect gain
**Total floorspace:** 1,200 sq. ft.
**Heated floorspace:** 1,200 sq. ft.
**Window area** —
  South: 400 sq. ft. East: 10 sq. ft.
  North: 16 sq. ft. West: 0
**Glazing:** two layers of glass
**Glazing orientation:** 8 degrees west of south
**Glazing angle:** vertical
**Thermal storage:** concrete, masonry
**Auxiliary heating:** wood, water-to-air heat pump
**Insulation** —
  Ceiling: fiberglass to R-38
  Walls: fiberglass to R-11
  Floor: rigid foam to R-16
  Foundation: rigid foam to R-16
  Windows: insulating shades, rigid foam panels
**Cost of materials and labor:** $40,000
**Cost per square foot:** $33
**Financing:** conventional loan, Renewable Energy Program grant ($5,400)
**Microclimate** —
  Degree-days: 7,723
  Average summer temperature: 69°F
  Average winter temperature: 35°F





Glendive

# Robert and Judy Zinda

## BUILDING DESCRIPTION

Set on top of a grassy hillside north of Glendive, this four-bedroom, underground home features a chemically treated wood foundation and walls. The Zinda house includes two garages, one at each end of the house, which also serve as vestibule mud rooms.

The exterior foundation wall consists of a treated 2-by-6-inch studwall resting on a 2-by-8-inch treated footing plate. This plate is pinned into a 2-foot-wide, reinforced concrete footing. Treated, ¾-inch exterior plywood sheaths the foundation wall. This plywood is covered with 1 inch of rigid foam and a vapor barrier of 4-mil polyethylene. The inside of the perimeter walls contains 6 inches of fiberglass insulation. After these walls were set in place, they were backfilled with native soil and gravel. A 4-inch-thick concrete slab floor was poured over a sand base to give the exterior wood walls lateral strength and to increase the home's heat-storing capacity.

The home's shed roof is supported by 6-by-14-inch laminated beams, each 36 feet long, and is decked with 2-by-6-inch tongue-and-groove pine. Sixty-pound tar paper covers the decking, which was sealed with an asphalt emulsion. A vapor barrier of 4-mil polyethylene, applied over the emulsion, is covered with 2 inches of rigid foam and 2 inches of bentonite. Six inches each of sand and soil cover all these components.

## SOLAR SYSTEM

Solar heat is gained directly through 200 square feet of triple-pane, double-vacuum, wood casement windows on the south wall. A 320-cubic-foot cinder block fireplace in the middle of the living room helps store collected heat. A small fan in the fireplace assists the natural convection of stored heat radiating from the fireplace. Vents in the top of a load-bearing partition wall in the middle of the house allow heat and light to enter bedrooms along the north wall. Double-layered curtains help prevent heat loss at night.

Because hot summer temperatures make cooling a major consideration for passive buildings in this area, a 2-foot overhang was added to the roof to shield the extensive south glazing from the summer sun.

## MAINTENANCE AND LIVABILITY

The Zindas' underground house is comfortable throughout the year. Indoor winter temperatures range from between 57° and 70°F during the day to a low of 50°F at night. Three and one-half cords of wood were burned during the past winter to supplement solar heating. Backup electric baseboard heaters were used only on very cold mornings and only for a couple of hours. The fireplace might collect more heat if it were reoriented along an east-west axis, thus increasing its exposure to the south glazing. Also, the storage capacity of the concrete floor is significantly diminished because the floor is carpeted.

Summer cooling is assisted by two 20-inch fans that circulate air through doors on the east and west sides of the home. The Zindas believe overheating could be reduced further by extending the roof overhang on the south to 4 feet, thereby preventing more late spring and early autumn sunlight from entering the windows.

The Zindas are satisfied with their wood foundation design; it provides a good moisture barrier and adequate structural strength at a cost less than concrete. Such a design also allows conventional fiberglass insulation to be used in the walls.

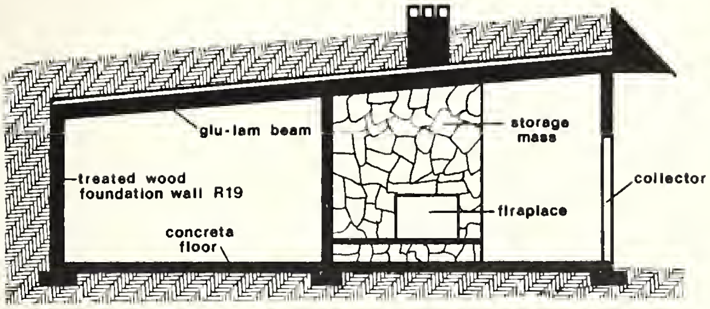
Only one problem arose during construction that can be attributed to the system's design: During the summer, the asphalt emulsion melted and bled through the roof decking, discoloring parts of the home's pine ceiling.

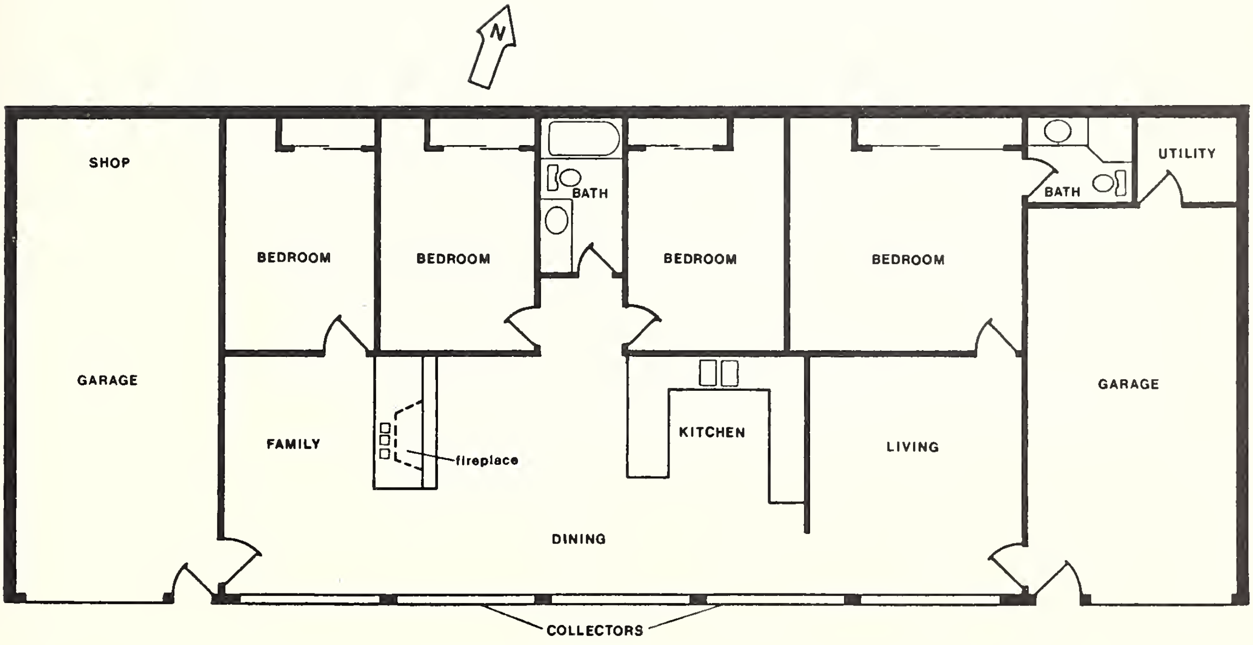
## BUILDING DETAILS

**Design type:** direct gain
**Total floorspace:** 2,560 sq. ft.
**Heated floorspace:** 1,900 sq. ft.
**Window area** —

| | |
|---|---|
| South: 200 sq. ft. | East: 0 |
| North: 0 | West: 0 |

**Glazing:** three layers of glass
**Glazing orientation:** 10 degrees east of south
**Glazing angle:** vertical
**Thermal storage:** rock, concrete
**Auxiliary heating:** wood, electric baseboard
**Insulation** —
  Ceiling: rigid foam to R-11
  Walls: fiberglass to R-19
  Floor: none
  Foundation: rigid foam to R-5.5
  Windows: double curtains
**Cost of materials and labor:** $68,000
**Cost per square foot:** $27
**Financing:** conventional loan
**Microclimate** —
  Degree-days: 7,774
  Average summer temperature: 68°F
  Average winter temperature: 34°F





# Summary and Conclusions

# MONTANA SUNPOWER

**MONTANA**

**DEPARTMENT OF NATURAL RESOURCES**

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**Energy Division ——— Helena, Mt. 59620**

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